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Preface

Cognitive maps have emerged as an important tool in modeling and decision making. In a nutshell they are signed di-graphs that capture the cause/effect relationships that subject matter experts believe exist in a problem space under consideration. Each node in the map represents some variable concept. These generally fall into one of several "hard" categories: physical attributes of the environment, characteristics of artifacts embedded in the problem space, or one of several "soft" areas: decisions being made, social, psychological or cultural characteristics of the decision makers, intentions, etc. Part of the value of cognitive maps is that these hard and soft concepts can be seamlessly mixed in them to build a more robust model of the problem.

Edges in the map connect nodes for which a causal relationship is believed to exist. The edge is directed from the causal node to the effect node. In a general cognitive map, the edges have integer strengths of 1, indicating direct causality, -1, indicating inverse causality, and 0, indicating no causal link. A special type of cognitive maps, a fuzzy cognitive map, allows fuzziness in the modeling of the edge strengths. Unlike nodes that have crisp values, edge strengths can have any fractional value on the interval [-1,1], with fractional values indicating partial causality. Thus, relationships such as A *somewhat* affects B, or A *really* causes B can be captured and incorporated in the map. The ability to model partial causality in the map gives this technique great value in problem spaces that have complex interactions between the physical environment, man-made machines and decisions by human operators.

The map is a true model in the sense that it has predictive capabilities. In a typical situation, a set of nodes with known values are designated *inputs*. These values are applied to the map and held constant at their known values. In much the same way that voltage or current sources are sources of energy in an electrical circuit, these input nodes represent sources of causality in the map. These input values are then propagated through the map, using a user defined thresholding function at each node to map its inputs to one of the permissible nodal values. The process is repeated multiple times for all nodes in the map until one of two meta-situations develops. Either the map will reach equilibrium in the sense that the nodal values remain constant, or it will reach a limit cycle, an oscillatory condition where a group of nodes change back and forth between two more sets of values.

Unlike a state machine, the actual sequence that the causal values work through the map are generally unimportant. The map itself represents a systems-level model. As such the one must view all nodal values in the map as contributing to an understanding of its behavior. Thus, system behavior is indicated by the totality of nodal values present after the input values have been applied and propagated through it to equilibrium.

Cognitive maps have several distinct advantages over other decision making tools like decision trees or Petri nets. First, because states of nodes are compared to states of nodes, a common numeric metric is not necessary for all values. Instead changes in the underlying concepts of nodes are compared to changes to the underlying concepts in other nodes. Thus, cognitive maps truly allow apples to be compared to oranges. Second, feedback is allowed in the map. With feedback, effects can be mitigated (negative feedback) or reinforced (positive feedback) by certain causes. Finally, the map can be pieced together from many smaller maps through common nodes. Subject matter experts can then provide a model within their domain of expertise, without the need to understand to any great detail the relevant concepts from other areas of interest. Each subject matter expert can then focus on what they know best contributing to the development of a robust systems model. Interestingly, feedback and feedforward loops often appear when the individual maps are pieced together that are not present individually. This may explain why "unseen" problems can develop in a system even though each subsystem is thoroughly tested and validated.

Completed cognitive maps are be used in two general ways: decision assessment and system diagnosis. In decision assessment a set of known values are applied to input nodes in the map and allowed to propagate to equilibrium with an eye to the nodal values that result. The goal with this process is to assess what changes in the state of the system can be expected given a set of initial conditions. Part of the value of this technique is that the input nodes are not fixed. They can change depending on the context and the available information.

In system diagnosis, one is more interested in what inputs give rise to a system state of interest. The map affords ways to make this determination. Since they can be become very complex quickly as nodes are added, the topology of the model itself can be used as a diagnostic tool. Using basic matrix techniques nodes and combinations of nodes can be identified that are linked to the output nodes of interest through some, possibly lengthy, chain of cause-effect relationships in the map. By identifying sets of these causal nodes, input values can then be applied to them to see if the system state under examination results.

The chapters in this book cover a spectrum of insights into the development, use and applications of cognitive mapping and fuzzy cognitive mapping techniques.

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Topic Maps as Indexing Tools in the Educational Sphere: Theoretical Foundations, Review of Empirical Research and Future Challenges

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1. Introduction

Topic Maps (International Organization of Standardization [ISO 13250], 1999; 2002) are a form of indexing that describe the relationships between concepts within a domain of knowledge and link these concepts to descriptive resources. Topic maps are malleable – the concept and relationship creation process is dynamic and user-driven. In addition, topic maps are scalable and can hence be conjoined and merged. Perhaps, most impressively, topic maps provide a distinct separation between resources and concepts, thereby facilitating migration of the data models therein (Garshol, 2004).

Topic map technologies are extensively employed to navigate databases of information in the fields of medicine, military, and corporations. Many of these proprietary topic maps are machine-generated through the use of context-specific algorithms which read a corpus of text, and automatically produce a set of topics along with the relationships among them. However, there has been little, if any, research on how to use cognitive notions of mental models, knowledge representation and decision-making processes employed in problem-solving situations as a basis for the design of ontologies for topic maps.

This chapter will first outline the theoretical foundations in educational psychology and cognitive information retrieval that should underlie the development of ontologies that describe topic maps. The conjectural analyses presented will reveal how various modes of online interaction between key stakeholders (e.g., instructors, learners, content and graphical user interfaces), as well as the classic information processing model, mental models and related research on problem representation must be integrated into our current understanding of how the design of topic maps can better reflect the relationships between concepts in any given domain. Next, the chapter outlines a selective review of empirical research conducted on the use of topic maps in educational contexts, with a focus on learner perceptions and cognitions. Finally, the chapter provides comments on what the future holds for researchers who are committed to the development, implementation, and evaluation of topic map indexes in educational contexts.

2. Topic maps: A primer

Topic maps separate the inter-related topics in a given body of knowledge from the actual resources that describe these topics. They provide context-based searches that can match context-specific search criteria entered by the user (Pepper, 2002; Garshol, 2004). As a search-and-retrieval technology, topic maps provide a method to code content in terms of topics, the relationships between these topics, and any additional informational resources associated with the target subject matter. This allows for greater flexibility in searching because the user not only gains access to information directly associated with a topic but also gets information regarding related topics. Results are returned not by keyword "hits" but rather by the concepts or ideas present in a corpus. A search will return fewer, more relevant "hits" matching the key word with the appropriate semantic context (Rath, 2000). Given their capability, topic maps can support learning within an online learning environment (OLE) in that content across functions can be integrated through search functionality triggered by a learner's query. Topic maps can help to provide the learner with a uniquely individualized tool that customizes how content is accessed and potentially organized.

Pepper (2002) refers to the elements of a topic map using the acronym TAO – Topics, Associations, and Occurrences. Let us consider a simple example of a topic map created to describe the body of knowledge related to e-learning. Topics pertinent to the subject matter of e-learning could include, for example, software platforms, learning management systems, learning content management systems, learning objects, industry standards, and interoperability, among others. Associations draw out the relationships between topics. For example, consider the following statement where the underlined portion details an association linking the topic "Interoperability Standards" to the topic "Metadata Schemes": "Interoperability standards are used in evaluating Metadata Schemes"; note also that this association is bi-directional, and hence, logically leads to the following statement: "Metadata Schemes are evaluated by Interoperability Standards". Occurrences point the user to resources that provide information about the topics themselves. An occurrence dedicated to the topic "Metadata Schemes" could be a pointer to an online article comparing the various metadata standards used in the industry. Topic maps also allow multiple naming conventions, which allow topics to be described in a variety of languages or by different titles according to user preference. Topic maps permit the assignment of metadata to information resources, similar to resources that possess XML tagging. Topics within a topic map can also be assigned a scope within which they are considered valid, thereby avoiding problems arising from the use of a topic in multiple contexts.

Arguably, the quality of the search results obtained through using a topic map depends largely on the topic map developer's ability to extract stakeholders' representations of the domain of knowledge being mapped. Proponents of the cognitive information processing (CIP) theory, proposed by Waugh and Norman (1965) and Atkinson and Shiffrin (1968), have explored the role of representations of ill-structured problems (Reitman, 1965) in various contexts (Voss, 1998; Voss & Post, 1988). Research has also shown that differences in problem solving ability between novices and experts can be partially attributed to their different problem representations (e.g., Voss et al., 1998; Torney-Purta, 1992). Taking this research into account, our development of topic maps is grounded in one or more expert's cognitive representations of the domain, and an analysis of the tasks to be performed by end-users who will be navigating the domain using the topic map.

Taxonomies, as a classification scheme or hierarchy of terms for cataloguing content can form the basis of a system for managing large, complex collections of information. While taxonomies and ontologies are terms that are used interchangeably, ontologies tend to include instantiations, constraints, and an extra element of theory – a notion that the structure actually describes reality, not just a method of organizing data (Kabel, deHoog, Wielinga & Anjewierden, 2004). As such, ontologies perhaps come closer to mental models of intellectual content. McGuiness (2001) contends that ontologies must exhibit certain required properties, namely, a finite controlled vocabulary, unambiguous interpretations of classes and term relationships, as well as strict hierarchical subclass relationships. In addition they may possess typical non-mandatory properties, such as value-restriction and specifications of arbitrary logical relationships between terms. Generally, these properties permit the construction of complex knowledge structures which give ontologies a significant advantage over other forms of organization. Following from our leanings toward a theory of CIP, we propose constructing a topic map for a given domain on a set of validated taxonomies and/or ontologies that emerge from an experts' view of that domain, including its topics, associations and occurrences.

3. Theoretical foundations

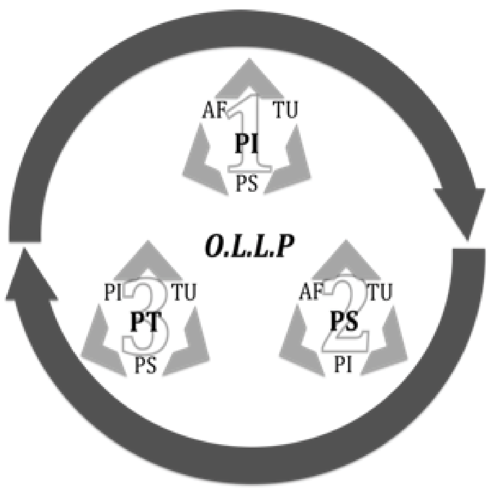
Information processing and its related theories should be instrumental in providing a framework for the design of ontologies that describe topic maps. In addition, investigating learning and its related processes in OLEs must take into account how learners regulate cognitions and metacognitions with respect to academic tasks, as well as how information retrieval is closely tied to elements of academic self-regulation. The following theoretical dissection of how specific elements of educational psychology-based literature intersect with those of the library sciences will illuminate the necessity of bridging the gap between these two seemingly disparate fields.

3.1 Theories of self-regulated learning

Academic self-regulation involves the strategic application and adaptation of learners' cognitive and metacognitive thought processes in influencing their own behaviour while tackling academic tasks (Pintrich, 2000; Zimmerman, 2000; Winne & Hadwin, 1998), taking into account their emotions (McCombs & Marzano, 1990) as well as motivational states (Pintrich, 2000; Pintrich & De Groot, 1991; Winne & Hadwin, 1998) within a specific learning context or environment (Winne & Hadwin, 1998). Some models of self-regulated learning (SRL) acknowledge the need for regulating all the five elements of cognition, affect, motivation, behaviour and context in explaining individual self-regulating processes. Most models of SRL promote goal-setting, strategic planning and execution of plans, reflection, self-monitoring, self-efficacy, and self-evaluation as essential skills to be developed by learners who engage with complex tasks requiring resource management skills, individual and group analyses of problem situations, as well as strategic use of feedback and contextually available resources. A critical, but under-researched concept subsumed within the notion of SRL is task understanding, which is considered to be a frontline phase of SRL (Venkatesh, 2008; Venkatesh & Shaikh, 2008).

Self-regulated learners apply both cognitive and metacognitive strategies, such as reflection and performance calibration, when completing academic tasks, taking into account contextual and task-specific conditions (Venkatesh, 2008; Venkatesh & Shaikh, 2008; Winne & Hadwin, 1998). While much is known about how to build self-regulatory competencies using sound instructional design principles, educational psychologists still struggle to understand and describe the interactions between the various individual components of self-regulated learning (SRL). Perhaps this is an artifact of classic conceptions of SRL as a complex, process-oriented theoretical construct; such an epistemological assumption makes it difficult to tease apart how learners think about the rationale for completing an academic task as well as how well they monitor their performance relative to the instructor's assessment criteria.

3.2 Ontological Levels of Learner Perceptions



PI: Perception of Instructor
PS: Perception of Self
PT: Perception of Task
AF: Affective Factors
TU: Task Understanding

Fig. 1. Ontological levels of learner perceptions (OLLP)

To better understand the implications of theories of SRL in the cognitive realm of information retrieval and use, we pose the following question: How is task understanding developed and affected by other self-regulatory processes that learners engage with while performing academic tasks? In proposing hierarchical and ontological levels of learner perceptions of feedback (Shaikh, 2008, provides the empirical evidence upon which the model is based) we attempt to shed new light on the effect of credibility, respect, trustworthiness, status and myriad of other factors as an influence on how students interpret feedback from certain instructors and their conception of 'self-as-learner'. When tackling a task for the first time, there is a hierarchical view to how students perceive the provider (i.e., the instructor) and the receiver (i.e., themselves) of feedback. For example, self-perceptions, such as confidence and motivational levels, take a back seat to how the provider of feedback is perceived by the learner, the student body as a whole and the educational environment. The learner bases feedback internalization on a multi-faceted system using the following hierarchical taxonomy:

- Tier 1 – Perception of Provider: Instructor must be seen as a viable source of information. If not, feedback is disregarded

- Tier 2 – Self-Perceptions: Learners' perception of self-worth, esteem, confidence and ability
- Tier 3 – Perception of Task: Inherent worth of the task and transferability to other scenarios

Further iterations or subsequent attempts of a given task are accompanied by other connections. Temporal effects of instructor feedback on learners' self-regulation while engaging in an academic task contends that learners prioritize a triad of perceptions in an ontological scheme, viz., the instructor, self-as-learner and task. Over time and through experience in a learning environment, learners choose which of these three perceptions take precedence, thereby influencing to varying degrees, how cognitions are employed to successfully meet the criteria for completion of a task.

For example, the perception of the provider can become dependent upon context and therefore it will be demoted from top tier status. Experiential factors, such as previous interaction with instructors, peer reviews or perceived expectations, play an extensive role in how a learner perceives their interactions and proficiency within a setting and therefore reliance upon instructor support and acknowledgement may decrease. With respect to extraneous variables (for example, context, experience, understanding of task and self, ego, previous interactions and respect) a hierarchical approach may not be all encompassing and an ontological description may prove worthwhile for further investigation. The ontological levels of learner perception (Figure 1) can serve as a framework for how students and instructors monitor progress and performance on academic tasks as well as possibly characterize the nature of the feedback internalization process, especially as learners navigate resources using an intuitively designed indexing mechanism such as a topic map. Boiled to its essence, these levels of perception provide a cognitive framework to investigate temporal and perspective-dependent aspects of task understanding.

3.3 Theories of Cognitive Information Retrieval (CIR)

The cognitive approach to information sciences began with De Mey's (1982) theories which were centred on the interaction between the user and the intermediary (human or computer). To this theory, Ingwersen (2000) adds the notion of the cognitive structures framed by the individual user, which are dependent on collective experiences, education, training and other individual and social cognitive factors. It is important to note that the cognitive psychological view of learning (as represented by the theory of SRL) would recommend that users' perceptions, epistemological beliefs as well as value frameworks influence and are, in turn, influenced by the cognitive structures that an individual brings to the information retrieval task. Ingwersen's view on the CIR theory, therefore, already attempts to bridge the gap between psychological theories of learning and the more human-computer interaction oriented theories of information science.

Ingwersen (2000) lays out the five major elements of the CIR theory. The first players are the information objects or knowledge sources as entities themselves, including their representations. These representations originate from the author(s) of the sources and necessarily depend on the representation(s) imposed by the indexer (human or machine) of the sources. The second set of players is the system structures, such as the retrieval algorithms, which are normally generated by the designers of an Information Retrieval (IR) system. These system structures depend on the indexer(s) of the sources as well. The third component refers to the interface functionalities of the IR system. These are created by system designers and may consist of cognitive structures imposed by human intermediaries in the IR process. The fourth element refers to the users' cognitive space, which consists of the perceptions about the work task and the situational perceptions surrounding the task. The cognitive space of the user also includes representations of the current state of knowledge, problem and uncertainty states. We would also venture to suggest that the CIR theory would accept that these cognitive spaces also subsume the cognitive and metacognitive strategies that the user has learnt in the past, and is able to draw upon to conduct, for example, means-ends analysis in problem-solving situations. The fifth and final piece of the CIR theory refers to the socio-organizational environments, including situational contexts, domain structures, the work tasks themselves, as well as access to strategies to solve problems.

3.4 Intersection between self-regulated learning and cognitive information retrieval

The description of CIR theory alludes to the concept of temporality in the IR process. This means that users of an IR system are necessarily bound by a time frame, which could provide a useful framework to understand how elements of the users' cognitive space interact with the other four elements of CIR theory. Similarly, cognitive assumptions about SRL also delineate a time-based perspective on how learners tackle academic tasks. However, in our opinion, theories of SRL fall short in focusing on what elements of task understanding one should devote attention to, in terms of measuring and promoting, in specific learning contexts. Additionally, keeping with the discussion of time frames, the issue that begs to be addressed is – at what point during an instructional event should a researcher expect to encounter changes in task understanding. Researchers of SRL have adopted a wide range of units of analyses, from individual students to timed classroom events, depending on which qualitative methodology is being used to investigate the phenomenon in question. CIR theory provides an excellent platform from which to test domain-specific theories of task understanding as a temporal phenomenon.

3.5 Task understanding

It remains now to uncover how task understanding is best served by viewing it under the lenses of both the theories of SRL and CIR. According to currently held theories of SRL, task understanding draws on two distinct, but interacting elements; these include individuals' perceptions of the academic task, as well as of themselves as a learner within a particular academic context. Learners' perceptions of the academic task include both the nature of the task, and the assessment criteria associated with the task. Learners reflect on their perceptions of the nature of the task, including: (a) the rationale for performing the task; (b) the procedures that need to be undertaken to perform the task and the required outputs; (c) the materials that are available to perform the task; as well as (d) the contextual conditions under which the task has to be performed. Learners also need to grapple with the assessment criteria that the instructor uses to judge their performance on the task. It is therefore clear that task understanding involves a close interaction between learners' perceptions and the instructor's perceptions of the academic task (Venkatesh & Shaikh, in press).

In addition to the task-associated elements, task understanding is influenced by the learner's knowledge of "self-as-learner". Such knowledge includes preferred learning styles and learning needs, prior content and task-specific knowledge, current motivational and emotional levels of anxiety and efficacy, as well as motivational and emotional levels associated with a specific type of task environment.

Ingwersen's (2000) model emphasizes a constant interaction between the cognitive space of the user and the socio-contextualized environment; these interactions influence human behavior during the IR event within the system. Moreover, dynamic interactions and interpretations change the information need and influence, in turn cognition and learning. As Ingwersen (2000, p.10) exhorts: "... it is essential to uncover the kind of cognitive factors or structures that triggers users' information needs and problem statements, for example, the reasons for users (mis)conceptions of classification structures or icons in systems. The cognitive nature of representative structures of information objects or knowledge sources are thus of interest directly". Ingwersen's conceptualization of CIR theory places great importance on elements of task understanding illuminated by current SRL theorists. According to CIR theory, the task and its perception by a user is considered just as valuable as the information need. In fact, Ingwersen also points out that the perception about the work task leads to the perceived information need. In a cognitive sense, the user's perception of a work task is more likely to be stable over the IR session time than the corresponding dynamic information need. Perception of work task is important, then, to provide the context necessary for the system to retrieve relevant information. However, initial empirical evidence reported in Venkatesh and Shaikh (2008) suggests that learners' information needs fluctuate as their task understanding improves. While these findings stand in contrast to Ingwersen's (2000) conjectures, it remains to be seen how future research formalizes the temporal aspects of task understanding in IR environments.

4. Review of empirical research on learners' cognitions while using topic maps

There exists a large community of practitioners and researchers who present and publish technically oriented work related to the development and implementation of topic maps (e.g., the annual Topic Map Research and Applications Conference [TMRA] in Leipzig, Germany). The purpose of our review of research is to provide an illustration of the cognitive orientation of researchers who assess learners' use of topic maps. Hence, this section will provide a selective review of empirical research conducted on the use of topic maps in educational contexts and its effects on learner cognitions.

Databases that were consulted for the purpose of this review include Association for Computing Machinery (ACM), Institute of Electrical and Electronic Engineers (IEEE), Explore, Education and Information Technology Digital Library ([EdITLib], hosted by the Association for the Advancement of Computing in Education [AACE]) as well as Education Information Resources Centre (ERIC). Searches focused on keywords of topic maps, extensible markup language topic maps (xtm) and its variations. Articles were selected based on whether they addressed educational applications of topic maps and provided evidence of learners' use of topic maps, whether from a usability or psychological standpoint. While reports of technology-related developments of topic map-based electronic learning environments (e.g., Dicheva & Dichev, 2004; 2006) and ontology construction (e.g., Dicheva & Dichev, 2005; Lenne, Cissé & Abel, 2005) were captured in our searches, the lack of empirical evidence about learning processes rendered these pieces ineligible for our review. The relevant articles include those conducted by Lavik and Nordeng (2004) as part of the Brainbank project, Oh and Park (2007) who conducted an experimental comparison of a topic map-enabled retrieval system versus a hierarchical browsing system, and Shih, Shih and Chen (2007) who built and evaluated a self-organizing (SOM) topic map. Also relevant is the body of work by Venkatesh and his colleagues which includes an experimental comparison of university learners' use of topic maps versus their use of search engines while completing academic tasks (Venkatesh et al., 2007), a mixed-method investigation of improvements in academic performance and self-regulatory mechanisms in graduate learners (Venkatesh, 2008) and finally, a qualitative analysis of how graduate learners' task understandings and monitoring of performance develop as they use topic maps to navigate text-based repositories while solving ill-structured writing tasks (Venkatesh & Shaikh, 2008). While it is still too early to discern how task understanding, metacognition and other self-regulatory processes unfold in information retrieval environments, the multi-method investigations presented in this section provide rich fodder to implement topic maps in educational contexts.

4.1 Lavik and Nordeng's Brainbank project

In a fascinating case study, Lavik and Nordeng (2004) outline how eighth grade pupils in Norway use a topic map-enabled suite of tools called Brainbank Learning (BBL) to enable cross-disciplinary learning. Lavik and Nordeng contend that through the use of the associative features of topic maps, the subjects taught to these eighth graders can be linked across the curriculum to develop competencies that span the contents (e.g., mathematics, physical/natural/social sciences, etc.). Lavik and Nordeng report on how learners become more aware of their learning processes and how these learners developed motivations to continue working with the BBL suite. In fact, the results point to learners improving their self-regulatory mechanisms, becoming more metacognitively cognizant of how to interact with the information retrieval systems they were engaging over the course of their study. Further research must be accomplished from a longitudinal standpoint to observe evidence of learning-based outcomes for technological advancements such as the BBL suite.

4.2 Oh and Park's experimental comparison of topic maps versus hierarchical organizers

In an experimental study, Oh and Park (2007) report on 20 learners' experiences in using topic map technologies versus an existing hierarchical classification system on a series of information retrieval tasks, ranging from simple to complex associative and cross-referencing tasks. Results of a counter-balanced experimental design revealed that learners using the topic map generally showed improved measures of completeness, ease of use, efficiency, appropriateness and satisfaction on tasks that were complex (associative and/or cross-referencing), but not on tasks that were simple or generated by the learners' own queries. However, the data do not reveal any information about the extent to which the topic map influenced learner cognitions.

4.3 Shih, Shih and Chen's investigation of self-organizing topic map

Shih, Shih and Chen (2007) present the results of a usability and instructional evaluation of a self-organizing topic map which indexed the content related to Chinese herbal medications. Data was collected in the form of surveys to 126 undergraduate learners enrolled in a course on Chinese herbs, as well as follow-up focus groups with a theoretical sample of learners. In general, data from the survey revealed that learners had positive perceptions towards the functional utility of the topic map. However, no data was collected with respect to cognitions or evidence of learning.

4.4 Venkatesh and Colleagues' implementations on topic maps in higher education

Following from the proposed theoretical bridge between academic self-regulation and cognitive information retrieval, Venkatesh and his colleagues have published a series of studies on the application of topic maps in a higher education context. First, Venkatesh et al. (2007) demonstrated improved performance on an ill-structured writing task for 18 learners in a topic map condition as opposed to 16 others in a keyword search condition. In a separate study, Venkatesh (2008) explored the development of task understanding in 38 graduate learners using topic maps to help complete an essay-writing assignment. A mixed-method procedure, which included multivariate repeated measures as well as inductive content analysis, yielded evidence of not only performance improvement, but also better task understanding. In a follow-up investigation, Venkatesh and Shaikh (2008), have conducted an in-depth qualitative analysis on 12 of these 38 learners, and uncovered how individual elements of task understanding, namely, perceptions for the rationale for completing the task, self-perceptions, and perceptions about the instructor engage in a tug-of-war while aiding learners to traverse the topic map with the objective of writing their essays.

5. Educational significance

Keeping the above theoretical discussions and review of empirical evidence regarding the conceptualization of learner cognitions in IR contexts, our goal now remains to provide synopses focusing on the significance of the educational implications and applications of topic maps. Within educational realms, the map itself can be considered a beneficial learning resource which supports learner concept acquisition regarding the classification and organization of a particular domain, the connections/relationships amongst concepts, the usefulness of the domain-based information and supporting terminology. Once created, completed and validated by subject matter experts, a topic map has the potential to provide learners with a domain-centric model, specifically a visual representation.

When users begin to browse a topic map, they can view resources that are linked to concepts that have inherent semantic relationships. One of the primary differences between conventional searches and topic map searches is that users can navigate a complex web of relationships. That being said, users can stumble upon relevant information which they may not have encountered using full-text or keyword searches. Topic maps, when integrated within the context of an OLE, can therefore provide the possibility for contextualized, discovery-based experiences for learners (Shaw & Venkatesh, 2005).

Topic maps have the ability to offer solutions to the ever-growing problem of using multiple or different terms and languages to describe a single over-arching concept. In content management and information science circles, the issues which arise from attempts to constrain users to describe content using a limited set of terms and to use these terms effectively and consistently are well known. One advantage of using topic map technology is that users and/or user groups can introduce and share their preferred terminology, keywords and labels for a particular subject. With appropriately designed topic map development tools, learners who are accessing courses in an OLE potentially can generate and use their own topic maps to help them navigate the information contained in the courses. Learners who are accessing courses in an OLE and are using appropriately designed topic map development tools will have the opportunity to conceptualize, generate and then use their self-generated topic maps that can help them navigate information and knowledge contained in the courses. The merging facility provided through topic maps allows learners to view similar content through multiple perspectives. Topic maps, being extensible, offer greater ease when compared with traditional approaches of integrating new insights. For example, in seasoned approaches new content classification requires that new meta-data fields be defined and populated, or consensus upon new keywords and their applications. Given the large body of research on potential automation of indexing and keyword extraction through the use of, for example, machine translation and natural language processing (where more research has been done), it would be assumed that its implementation within topic-map based environments is feasible, however they have been limited in their success. Topic maps operate at a level or levels of abstraction above regular meta-data, therefore, they may offer sophisticated means to develop indices that do not necessarily require that each resource be manually indexed. The simplification of updating and extending the relationships seen in topic maps, without the need to alter the information resources themselves, eases administration of courses in OLEs. When course material in topic map based OLEs is updated, existing topics and associations can be freely edited and new topics can be added to the existing ontological structure.

5.1 Practical implications

While it has been established in cognitive psychological terms that learners' task understandings are a crucial component of academic self-regulatory activities, the review of research offers specific suggestions on how individual components of task understanding can be ameliorated while learners are tackling ill-structured writing tasks using online repositories of information. We recommend using topic maps to provide opportunities for learners to view assessment criteria through multiple perspectives and various interactions (e.g., learner-learner, learner-instructor, learner-content).

Learners should be allowed to control their navigation in these online repositories by harnessing the associative powers of indexing technologies like topic maps. Individual preferences, such as browsing by subject, author, essay or grade could be better facilitated by allowing users to create their own topic-centric associations, thereby personalizing their route through the complex webs of information in online repositories. Note, however, that Venkatesh et al. (2007) have warned that user-generated indexes must undergo strict content validation, without which the domains represented by technologies such as topic maps are rendered useless due to the specious nature of the content therein.

Finally, how context and/or learner dependent is information need? We can partially answer this question by taking the easy route and pointing to individual differences and preferences. However, that would belie the complex dance that task understanding and information need engage in when learners' cognitions are commissioned in the context of online retrieval of information. While we are aware that information needs morph as the process of improvement of task understanding is undertaken by learners, future research should explore specific conditions which might govern how, when and why these needs must react to changes in learners' cognitions.

6. References

Atkinson, R., & Shiffrin, R. (1968). Human memory: A proposed system and its control processes. In K. Spence and J. Spence, eds., *The Psychology of Learning and*

Motivation: Advances in Research and Theory - Volume 2, New York, NY: Academic Press, p. 90-197.

De Mey, M. (1982). *The cognitive paradigm: An integrated understanding of scientific development.* Dordrecht, The Netherlands: D. Reidel Publishing Company.

Dicheva, D., & Dichev, C. (2004). A framework for concept-based digital course libraries. *Journal of Interactive Learning Research,* 15 (4), p. 347-364.

Dicheva, D., & Dichev, C. (2005). Authoring educational topic maps: Can we make it easier? In, *Proceedings of the 5th IEEE International Conference on Advanced Learning Technologies (ICALT) 2005* (pp. 216-218). Kaohsiung, Taiwan: ICALT.

Dichev, C., & Dicheva, D. (2006). TM4L: Creating and browsing educational topic maps. *British Journal of Educational Technology, 37* (3), 391-404.

Ingwersen, P. (2000). Cognitive Information Retrieval. In M. Williams, ed. *Annual Review of Information Science and Technology, Volume 34, 1999-2000*. Medford, NJ: Information Today, Inc. p. 3 -52.

International Organization of Standardization. (1999). *ISO 13250 Topic Maps - First Edition* [Online]. Available at : http://www.y12.doe.gov/sgml/sc34/document/0129.pdf

International Organization of Standardization. (2002). *ISO 13250 Topic Maps – Second Edition* [Online]. Available at: http://www.y12.doe.gov/sgml/sc34/document/0322_files/iso13250-2nd-ed-v2.pdf

Kabel, S., de Hoog, R., Wielinga, R., & Anjewierden, A. (2004). The added value of task and ontology-based markup for information retrieval. *Journal of the American Society for Information Science and Technology, 55* (4), 348-382.

Lavik, S. & Nordeng, T. W. (2004). Brainbank learning—building topic maps-based e-portfolios. In *Proceedings of First International Conference on Concept Mapping*, Pamplona, Spain, (pp. 401–408). Navarra, Spain: Universidad Pública de Navarra.

Lenne, D., Cissé, O. & Abel, M. (2002). e-Learning and Knowledge Management: the MEMORAE project. In G. Richards (Ed.), *Proceedings of World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education 2002* (pp. 61-66). Chesapeake, VA: AACE. Available at: http://www.editlib.org/p/8918.

McCombs, B. L., & Marzano, R. J. (1990). Putting the self in self-regulated learning: The self as an agent in integrating will and skill. *Educational Psychologist, 25*, 51-69.

McGuinness, D.L. (2001). Ontologies Come of Age. In Fensel, D., Hendler, J., Lieberman, H. & Wahlster, W. (eds.), *Spinning the Semantic Web: Bringing the World Wide Web to Its Full Potential.* Cambridge, MA: MIT Press.

Garshol, L. M. (2004). Metadata? Thesauri? Taxonomies? Topic Maps! Making sense of it all. *Journal of Information Science 30* (4), 378-391.

Oh, S. G. & Park, O. N. (2007). Design and users' evaluation of a topic maps-based Korean Folk Music Retrieval System. In L. Maicher, A. Sigel and L. M. Garshol (Eds.), Topic Maps Research and Applications 2006, pp. 74-89. Berlin: Springer-Verlag.

Pepper, S. (2002). *The TAO of Topic Maps* [Online]. Available http://www.ontopia.net/topicmaps/materials/tao.html

Pintrich, P. R. (2000). The role of goal orientation in self-regulated learning. In M. Boekaerts, P. R. Pintrich, & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 451-502). San Diego, CA: Academic Press.

Pintrich, P. R., & De Groot, E. V. (1991). Motivational and self-regulated learning components of classroom academic performance. *Journal of Educational Psychology, 82*, 33-40.

Rath, H. H. (2000). Topic maps: Templates, topology, and type hierarchies. *Markup Languages: Theory & Practice, 2* (1), 45-64.

Reitman, W. (1965). *Cognition and thought*. New York, NY: John Wiley.

Shaikh, K. (2008). *Exploring the existence of motivational and cognitive variables affecting the perspectives and internalization of instructor-given feedback*. Unpublished thesis in the Department of Education, Concordia University. Montreal, Canada.

Shih, B. -J., Shih, J. -L., & Chen, R.-L. (2007). Organizing learning materials through hierarchical topic maps: an illustration through Chinese herb medication. *Journal of Computer Assisted Learning*, 23, 477-490.

Shaw, S., & Venkatesh, V. (2005). The missing link to enhanced course management systems: Adopting learning content management systems in the educational sphere. In P. McGee, C. Carmean and A. Jafari, eds. *Course Management Systems for Learning: Beyond Accidental Pedagogy*. Hershey, PA: Idea. p. 206-231

Torney-Purta, J. (1992). Cognitive representations of the political system in adolescents: The continuum from pre-novice to expert. In H. Haste and J. Torney-Purta, eds. *The Development of Political Understanding: A New Perspective*. San Francisco, CA: Josey-Bass. p. 11-25.

Venkatesh, V. (2008). Topic maps as indexing tools in e-learning: Bridging theoretical and practical gaps between information retrieval and educational psychology. *International Journal of Advanced Media and Communication, 2* (3). 221-235.

Venkatesh, V., & Shaikh, K. (2008). Investigating task understanding in online repositories equipped with topic map indexes: Implications for improving self-regulatory processes in graduate learners. *International Journal of Technologies in Higher Education, 5*(3), 22-35

Venkatesh, V., Shaw, S., Dicks, D., Lowerison, G., Zhang, D., & Sanjakdar, R. (2007). Topic Maps: Adopting user-centred indexing technologies in course management systems. *Journal of Interactive Learning Research,* 14 (3). p. 429-450.

Voss, J. (1998). On the representation of problems: An information-processing approach to foreign policy decision making. In D. Sylvan and J. Voss, eds. *Problem Representation in Foreign Policy Decision Making*. Cambridge, UK: Cambridge University Press. p. 8-26.

Voss, J. F., & Post, T. A. (1988). On the solving of ill-structured problems. In M. T. H. Chi, R. Glaser, & M. J. Farr (Eds.), *The Nature of Expertise* (pp. 261-285). Hillsdale, NJ: Lawrence Erlbaum.

Voss, J. F., Wiley, J., Kennet, J., Schooler, T. E., & Silfies, L. N. (1998). Representations of the Gulf crisis as derived from the U. S. Senate debate. In D. A. Sylvan & J. F. Voss, *Problem Representation in Foreign Policy Decision Making* (pp. 279-302). Cambridge, UK: Cambridge University Press.

Waugh, N., & Norman, D. (1965). Primary memory, *Psychological Review, 72*, p. 89-104.

Winne, P. H., & Hadwin, A. F. (1998). Studying as self-regulated learning. In D. J. Hacker, J. Dunlosky, & A. C. Graesser (Eds.), *Metacognition in educational theory and practice* (pp. 277-304). Malwah, NJ: Erlbaum.

Zimmerman, B. J. (2000). Attaining self-regulation: A social cognitive perspective. In M. Boekaerts, P. R. Pintrich, & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 13-39). San Diego, CA: Academic Press.

2

A Cognitive Approach for Performance Measurement in Flexible Manufacturing Systems using Cognitive Maps

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1. Introduction

Cognition is a process, which includes perceiving, storing, remembering, re-calling, and using the senses. In other words, cognition consists of the physical and mental activities of understanding, commenting on, and learning to perception of our world. The term cognitive approach comes from the behavioral science of psychology.

It was challenged around the beginning of the 1980s by the concept of cognitive ergonomics that mental work (thinking) is far more important than manual work (doing) (Hollnagel, 2001). Cognitive systems mean that the analysis cannot be based on a structural decomposition of human-machine systems, but have to be referred to the notion of acting system which means that humans and machines are seen together (Lang et al., 2000; Morray, 1998).

As computer-based systems (modern manufacturing systems) become more complex, performance of the human in such systems become more critical due to the assignment of cognitive and decision making tasks to the jobshop. The rapid development of manufacturing technology requires operators to learn new skills continuously. Since humans play a critical role, the interaction between tasks and human skills must be thoroughly understood so that corporations can adapt efficiently to new technologies (Brezocnik et al., 2003; Suwingnto et al., 2000). Besides, the classical performance measurement systems are insufficient to measure human and system performance factors.

Manufacturers face an increasingly uncertain external environment as the rate of the change in customer expectations, global competition and technology accelerates, hence manufacturing flexibility has become a critical dimension. A Flexible Manufacturing System (FMS) combines NC and CNC machines, a material handling system (MHS), and a computer system to control the work. These systems are appropriate for mid-volume and mid-variety manufacturing. The components of the systems are: (1) NC and CNC machines (2) Robots and (3) Direct control unit for material handling system and CNC machines (DNC) (Zhang et al., 2003).

A hierarchy is an efficient way to organize a complex system, as it is efficient structurally when representing the system and when controlling and passing information down the system. However, many decision-making problems like cognitive performance evaluation

cannot be structured hierarchically because they involve the interaction and dependence between levels on the constructed cognitive maps. Structuring a problem involving functional dependence allows for feedback among clusters. These systems can be analyzed with a network structure like using cognitive maps. Besides, cognitive maps are expressed the positive and negative dependences (relationships) among factors together. The Multi-Criteria Decision Making (MCDM) methods are easy way to organize these systems.
The studies on the cognitive maps have begun several years ago, and ever increasingly continued in the last years. Cognitive maps have been used in several areas. Behavioral and neurosciences are the primary fields (Sato & Yamaguchi, 2009) and medicine, biology (Byrne et al., 2009; Gras et al., 2009), zoology, advanced manufacturing systems, risks and performances of projects, computers and artificial intelligence, fuzzy systems (Gras et al., 2009; Kim et al., 2008; Fekri et al., 2009), e-business (Xirogiannis & Glykas, 2007; Lee & Ahn, 2009), and education (Hossain & Brooks, 2008) can be given working areas as example. Nowadays, the studies on the advance manufacturing systems and performance of the models have been performed widely in the recent literature (Eraslan & Kurt, 2007; Kim et al., 2008; Kim et al., 2009; Lee et al., 2009; Fekri et al., 2009) but the combination of the MCDM methods and cognitive maps have not.
In this study, one of the biggest molding factories of Europe is selected and the cognitive maps which are specific to the FMS system performance structure are established. Developing quantitative models for determination of cognitive performance factors is studied using the combination of cognitive mapping technique and the MCDM methods which are Analytical Hierarchy Process (AHP) and Analytical Network Process (ANP) to identify these factors, express, prioritize and classify them quantitatively. The factors and subfactors affecting the system performance of Flexible Manufacturing Systems are prioritized and comparatively analyzed.
In the next section, the MCDM methods used in this study are briefly explained. In the third section, the application steps are stated and the prioritization with MCDM methods is performed. Finally, the research results and conclusion remarks are summarized in the conclusion and discussion section.

2. The Multi-Criteria Decision Making (MCDM) methods

In this section, the multi-criteria decision making (MCDM) methods which are used in this study are briefly explained.

2.1 Analytical Hierarchy Process method (AHP)

The initial study identified the multi-criteria decision technique known as the Analytic Hierarchy Process (AHP) to be most appropriate for solving complicated problems. AHP was first introduced by Saaty and used in different decision-making process related to production (Bozdag et al., 2003; Buyukozkan et al., 2004), energy (Xiaohua & Zhenmin, 2002), investment (Suresh & Kaparthi, 1992), and location (Badri, 1999; Kuo et al., 2002). AHP is a comprehensive framework that is designed to cope with the intuitive, the rational, and the irrational when we make multi-objective, multi-criterion, and multi-actor decisions, with or without certainty for any number of alternatives. An advantage of the AHP over other MCDMs is that AHP is designed to incorporate tangible as well as intangible criteria especially where the subjective judgments of different individuals constitute an important part of the decision process. The basic assumptions of AHP are that it can be used in functional independence of an upper part or cluster of the hierarchy from all its lower parts and the criteria or items in each level. AHP uses the Saaty's 1-9 scale as shown in Table 1 (Saaty, 1996).

Low	1	Equal (low low)
	2	Between (medium low)
	3	Moderate (high low)
Medium	4	Between (low medium)
	5	Strong (medium medium)
	6	Between (high medium)
High	7	Very strong (low high)
	8	Between (medium high)
	9	Extreme (high high)

Table 1. Fundamental scale of absolute numbers for pairwise comparisons

2.2. Analytical Network Process method (ANP)

Many decision-making problems cannot be structured hierarchically because they involve the interaction and dependence of higher level elements on lower level elements (Saaty, 1986; Saaty, 1996). Structuring a problem involving functional dependence allows for feedback among clusters. This is a network system. Saaty suggested the use of AHP to solve the problem of independence on alternatives or criteria, and the use of ANP to solve the problem of dependence among alternatives or criteria.

The ANP, also introduced by Saaty, is a generalization of the AHP (Saaty, 1996). Whereas AHP represents a framework with a uni-directional hierarchical AHP relationship, ANP allows for complex interrelationships among decision levels and attributes. The ANP feedback approach replaces hierarchies with networks in which the relationships between levels are not easily represented as higher or lower, dominant or subordinate, direct or indirect (Meade & Sarkis, 1999). For instance, not only does the importance of the criteria determine the importance of the alternatives, as in a hierarchy, but also the importance of the alternatives may have impact on the importance of the criteria. Therefore, a hierarchical structure with a linear top-to-bottom form is not suitable for a complex system.

The ANP is a coupling of two parts. The first consist of a control hierarchy or network of criteria and subcriteria that control the interactions in the system. The second is a network of influences among the elements and clusters. The network varies from criterion to criterion and a supermatrix of limiting influence is computed for each control criterion. Supermatrix is a two-dimensional matrix of elements by elements. The priority vectors from the paired comparisons are placed in the appropriate column of the supermatrix. As the supermatrix is built in this way, the sum of each column corresponds to the number of comparison sets. Finally, each of these supermatrices is weighted by the priority of its control criterion and the results are synthesized through addition for all the control criteria. In addition, a problem is often studied through a control hierarchy or system of benefits, a second for costs, a third for opportunities, and a fourth for risks. The synthesized results of four control systems are combined by taking quotient of the benefits times the opportunities to the costs times the risks to determine the best outcome. The process of ANP comprises of four major steps:

1. Model construction and problem structuring,
2. Pairwise comparisons matrices and priority vectors,
3. Supermatrix formation and determining limit supermatrix,
4. Synthesize the results.

Over the years, ANP, a comprehensive multi-purpose decision method, has been widely used in solving many complicated decision-making problems. Meade and Sarkis (1999) used ANP in a methodology they developed to evaluate logistic strategies and to improve production speed. Also in a separate study performed by Lee and Kim (2001), ANP is used in the interdependent information system project selection process. In addition to these studies Sarkis (2002), in a model he developed for the purpose of strategic supplier selection; Mikhailov and Singh (2003), in the development process of a decision support system; Yurdakul (2003), in a model he built in order to evaluate long term performances of production systems; Momoh and Zhu (2003), in specifying optimal production schedules; Niemira and Saaty (2004), in financial crisis forecasting, used ANP method.

3. Prioritization of the cognitive factors utilizing MCDM methods for FMS system performance

In this section, AHP and ANP models are developed to prioritize of the performance measurement factors. At the beginning, a systematic way must be put forward to consider, determine and calculate the cognitive performance factors. The hierarchical structures could be established via cognitive maps' specifications, and the factors of cognitive performance for the FMS system could be designated. In this study, the steps stated below are followed and each step is explained briefly in the following sections:

i. Determine the cognitive performance factors for the FMS system and their importance levels via brainstorming with system experts and managers.
ii. Establish the hierarchy levels for individual and system performance using the factors' importance and experts' view.
iii. Determine the effects of dependences among factors, i.e., the interrelations among the factors using cognitive maps.
iv. Examine the vertical relations with AHP method i.e., establish the cognitive performance decision matrices (CPDM) via pairwise comparisons and calculate the weights.
v. Determine the dependences of the factors for each level and examine the new effects with ANP method.
vi. Calculate the global weights with both MCDM methods, compare each other, and analyze the differences.

3.1 Determination of the cognitive system performance factors

The criteria in the developed model are determined with an expert team including the participations of related department managers, production chiefs, and the authors of this study. Firstly, the team members propose criteria to use in the performance model. Later, the proposed criteria are evaluated together and the final criteria to put into model are determined. Totally 22 factors and subfactors are determined. The structure of the model about decision problem is stated, and adding the connections between the factors and the Cognitive Map (network model) was developed (Eraslan&Kurt, 2007).

3.2 Establishing the hierarchy of the factors using cognitive maps

The developed model consists of four main criteria and 18 subfactors in 3 levels which are shown in Fig. 1. At the top of the hierarchy, there exists the goal of the problem which determines the prioritization of cognitive factors affects FMS system performance. Expert team decides that flexibility (FLEX), production speed (PS), product variety (PV), and customer satisfaction (CS) have some importance levels for the determined goal in the first level. Material (MF), operation (OF), material handling (MHF), and rotating flexibilities (RF) are the subfactors of the flexibility; flow rate (FR) and the buffers (BU) are the subfactors of the production speed; product quality (PQ) and total cost (TC) are the subfactors of the customer satisfaction in the second level. The subfactors of material handling are robots (RO), AS/RS Systems (ASRS), and Automated Guided Vehicles (AGV); the subfactors of flow rate are NC (NC), CNC (CNC), and DNC (DNC); and finally the subfactors of total cost are setup cost (SC), purchasing cost (PC), labor cost (LC), and production volume (VO) stated in the third level.

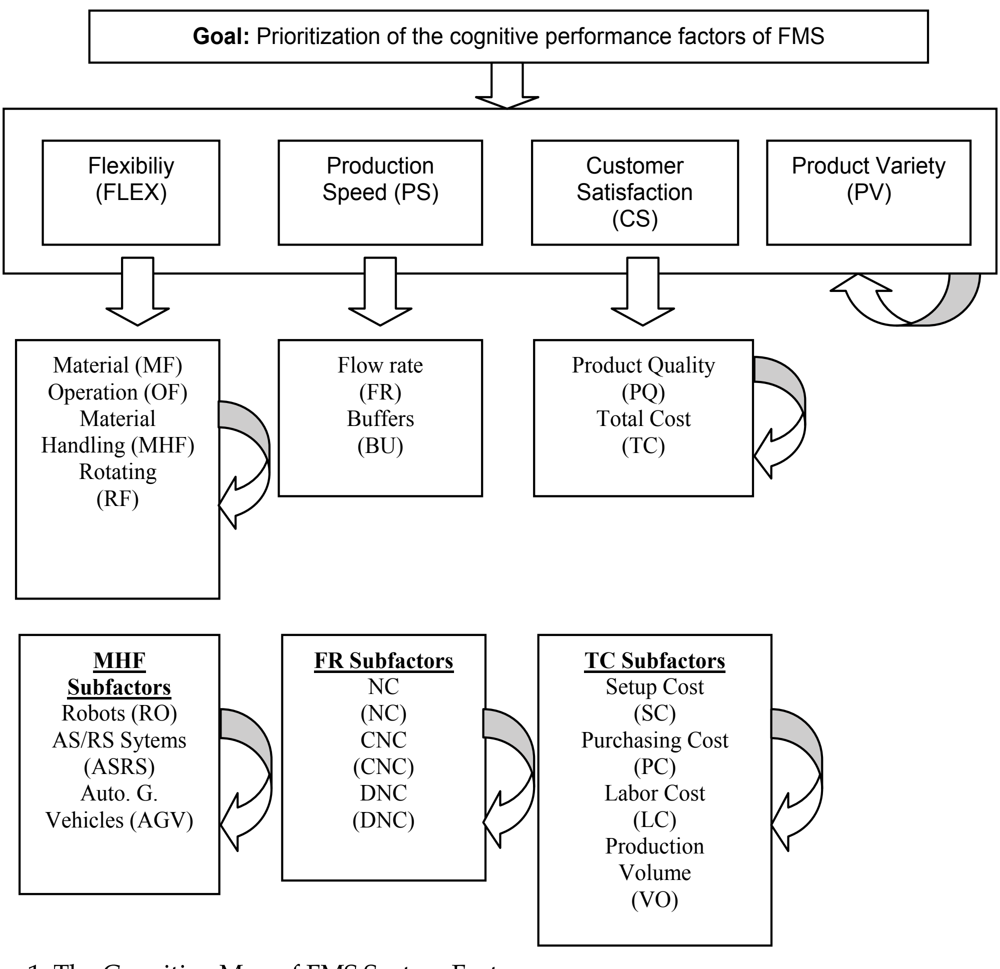

Fig. 1. The Cognitive Map of FMS System Factors

3.3 Prioritization of the performance factors with AHP method

After setting up the cognitive map and required connections, pairwise comparisons are performed. In order to do the pairwise comparisons, a questionnaire is designed and the views of expert team members are taken therein. While taking the judgment for each individual in expert team, interviews were made separately each other by using questionnaire technique. The scale that takes integer values between 1 and 9 were used in the recommended technique (Saaty, 1996). The valuation scales in the pairwise comparisons are those, where 1 is equal importance, 3 is moderate importance, 5 is strong importance, 7 is very strong or demonstrated importance, and 9 is extreme importance. Even numbered values will fall in between importance levels as shown in Table 1.

Pairwise comparisons were based on upper level main criteria. Weights of the criteria must be determined first. For this reason, the expert team made their pairwise comparisons about strategic criteria and notified their judgments according to overall goal. As a result, pairwise comparison matrix is obtained to determine the criteria priorities. The pairwise comparison matrices are obtained for second and third level in the hierarchy without taking into consideration the relationships among factors. Then, overall weights are calculated as shown in Table 2.

Level 1	Factors	FLEX	PS	CS	PV
	Weights	0.526	0.249	0.085	0.141
Level 2	Subfactors	MF	OF	MHF	RF
	Weights	0.070	0.508	0.193	0.229
	Subfactors	FR	BU	PQ	TC
	Weights	0.667	0.333	0.750	0.250
Level 3	Subfactors	RO	ASRS	AGV	
	Weights	0.633	0.106	0.260	
	Subfactors	NC	CNC	DNC	
	Weights	0.074	0.283	0.643	
	Subfactors	SC	PC	LC	VO
	Weights	0.079	0.151	0.254	0.516

Table 2. Overall weights of the main criteria and the subfactors

3.4 Prioritization of the performance factors with ANP method using the dependences among factors

This network consists of four kinds of subnetworks: flexibility (FLEX), production speed (PS), product variety (PV), and customer satisfaction (CS) each of which represents the relationship of its own clusters and elements as shown in Fig. 2.

On the basis of the dependences shown in Fig. 2., dependence matrix is organized utilizing pairwise comparison matrices. The dependent weights ($CPDM_{GOAL}$) are obtained multiplying with the first weights of the factors and pairwise comparison matrix given in Table 2.

$$CPDM_{GOAL} = \begin{bmatrix} 1 & 1/3 & 0 & 1/2 \\ 0 & 2/3 & 1/3 & 0 \\ 0 & 0 & 1/3 & 0 \\ 0 & 0 & 1/3 & 1/2 \end{bmatrix} * \begin{bmatrix} 0.526 \\ 0.249 \\ 0.085 \\ 0.141 \end{bmatrix} = \begin{bmatrix} 0.650 \\ 0.213 \\ 0.046 \\ 0.094 \end{bmatrix}$$

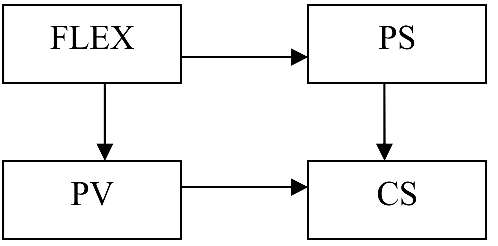

Fig. 2. Dependences (interrelations) among main factors in the first level (main criteria: GOAL).

It is shown that a significant difference is appeared when compare with the weights without using dependences (AHP) more particularly for FLEX and PV.

In the next step, the dependences among the subfactors in the second level of the cognitive map are analyzed. These dependences are viewed in the Fig. 3.

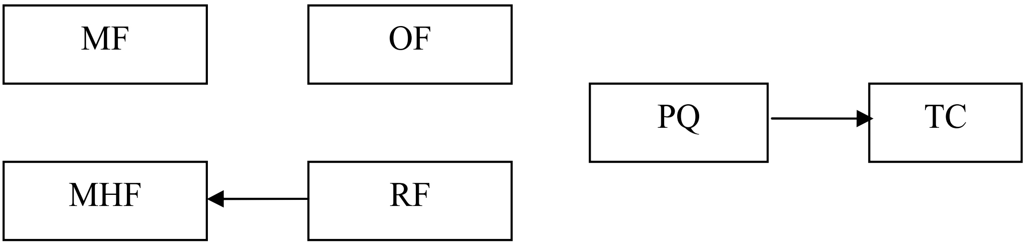

Fig. 3. Dependences among subfactors in the second level (FLEX, CS).

Using the dependences of Fig. 3, the dependence matrices are obtained for both groups with pairwise comparison matrices. Then, dependent weights of subfactors are calculated multiplying the first weights of subfactors. These calculations are given below ($CPDM_{FLEX}$, $CPDM_{CS}$):

$$CPDM_{FLEX} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 2/3 & 0 \\ 0 & 0 & 1/3 & 1 \end{bmatrix} * \begin{bmatrix} 0.070 \\ 0.508 \\ 0.193 \\ 0.229 \end{bmatrix} = \begin{bmatrix} 0.070 \\ 0.508 \\ 0.129 \\ 0.293 \end{bmatrix}$$

$$CPDM_{CS} = \begin{bmatrix} 1 & 2/3 \\ 0 & 1/3 \end{bmatrix} * \begin{bmatrix} 0.750 \\ 0.250 \end{bmatrix} = \begin{bmatrix} 0.920 \\ 0.080 \end{bmatrix}$$

After the calculations of $CPDM_{FLEX}$, $CPDM_{CS}$ matrices, it is shown that the weights of the subfactors of MF and OF are remained same expectedly in the FLEX group but the weights of MHF and RF is significantly changed. In the CS group, the weight of the subfactor PQ is increased but the TC is decreased.

In the third step, the dependences of the subfactors in the third level of the cognitive map are determined and analyzed. The interrelations of the subfactors are shown in Fig. 4.

On the basis of Fig. 4, the dependence matrices are constituted for three groups utilizing pairwise comparison matrices. Multiplying the first weights of subfactors and dependence matrices, dependent weights of subfactors are calculated. These calculations are given below ($CPDM_{MHF}$, $CPDM_{FR}$, $CPDM_{TC}$):

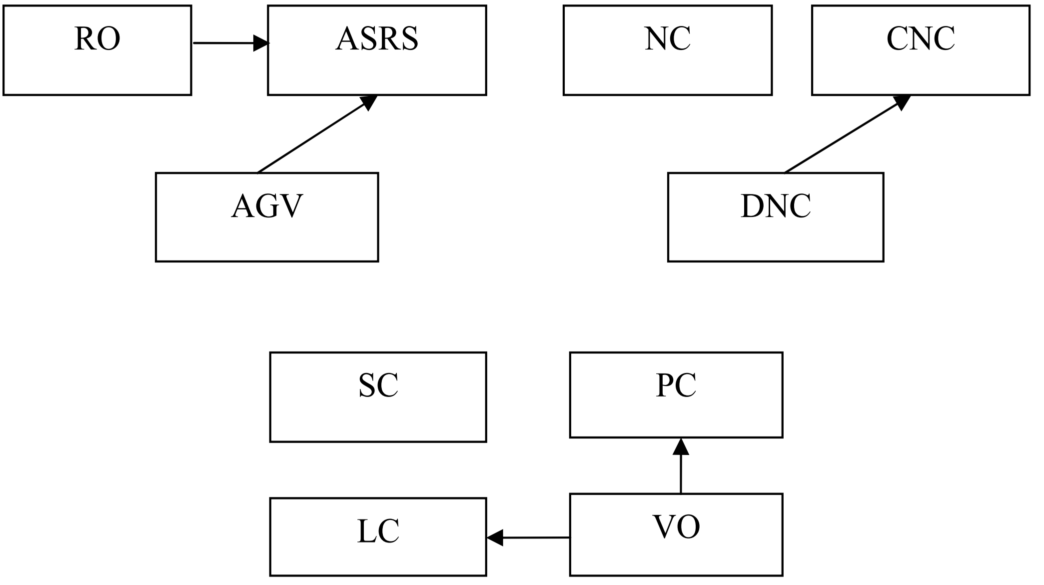

Fig. 4. Dependences among subfactors in the third level (MHF, FR, TC).

$$CPDM_{\mathrm{MHF}} = \begin{bmatrix} 1 & 1/3 & 0 \\ 0 & 1/3 & 0 \\ 0 & 1/3 & 1 \end{bmatrix} * \begin{bmatrix} 0.633 \\ 0.106 \\ 0.260 \end{bmatrix} = \begin{bmatrix} 0.668 \\ 0.037 \\ 0.295 \end{bmatrix}$$

$$CPDM_{\mathrm{FR}} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 3/4 & 0 \\ 0 & 1/4 & 1 \end{bmatrix} * \begin{bmatrix} 0.074 \\ 0.283 \\ 0.643 \end{bmatrix} = \begin{bmatrix} 0.075 \\ 0.212 \\ 0.713 \end{bmatrix}$$

$$CPDM_{TC} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 3/4 & 0 & 0 \\ 0 & 0 & 9/10 & 0 \\ 0 & 1/4 & 1/10 & 1 \end{bmatrix} * \begin{bmatrix} 0.079 \\ 0.151 \\ 0.254 \\ 0.516 \end{bmatrix} = \begin{bmatrix} 0.079 \\ 0.114 \\ 0.228 \\ 0.579 \end{bmatrix}$$

Depend on the interrelations of the third level, some particular changes of the subfactors are observed. The significant changes are calculated for subfactor ASRS in MHF group; for subfactors CNC and DNC in FR group; and for subfactor VO in TC group.

3.5 Comparison of the results

First, the global weights of factors/subfactors are calculated with AHP method accepting that the subfactors are independent each other or in the same level. Then, the interrelations among factors/subfactors are considered using the feature of the ANP method.
Thus, the new and more sensitive weights are calculated and more accurate results are obtained. These results are comparatively analyzed (Saaty, 2006) and given in the Table 3.

Level 1	Factors	FLEX	PS	CS	PV
	AHP	0.526	0.249	0.085	0.141
	ANP	0.650	0.213	0.046	0.094
Level 2	Subfactors	MF	OF	MHF	RF
	AHP	0.070	0.508	0.193	0.229
	ANP	0.070	0.508	0.129	0.293
	Subfactors	FR	BU	PQ	TC
	AHP	0.667	0.333	0.750	0.250
	ANP	0.667	0.333	0.920	0.080
Level 3	Subfactors	RO	ASRS	AGV	
	AHP	0.633	0.106	0.260	
	ANP	0.668	0.037	0.295	
	Subfactors	NC	CNC	DNC	
	AHP	0.074	0.283	0.643	
	ANP	0.075	0.212	0.713	
	Subfactors	SC	PC	LC	VO
	AHP	0.079	0.151	0.254	0.516
	ANP	0.079	0.114	0.228	0.579

Table 3. The comparison the weights of factors/subfactors for AHP and ANP Methods

4. Conclusion and discussion

In this study, a cognitive approach for the factors effecting performance of FMS system have been developed and explained using cognitive maps. The benefits of this approach show four new improvements:

- The complex structure of cognitive performance is established for a specific FMS system by cognitive mapping technique.
- The MCDM methods i.e., AHP and ANP have been applied to the dynamic structure of the system and the decisions of the production managers and related stuffs are included in decision processes. The results are comparatively analyzed; more sensitive results are obtained utilizing interrelations for factors and subfactors.
- The dynamic nature of the internal and external environments of jobshop has been included to the performance measurement system.
- The factors that affect performance can be identified; their effects can be quantified effectively by this approach.

According to the results, comparing the AHP and ANP matrices, the 17 of the global weights of the cognitive performance factors/subfactors are changed, 5 of them are remained stable.

The proposed model can help managers to evaluate the levels of the impact to each factor and make the interrelations clearly on overall performance. Therefore this model can be

regarded as a detailed Decision Support System (DSS) to monitoring and determine the cognitive problems in workplace for modern manufacturing systems in future studies.
The overall effect of factors can be designed a investigating system by using performance charts to follow the dynamic behavior of cognitive systems in certain periods, since they have to be monitored frequently or occasionally and do not remains stable.

5. References

Badri, M.A. (1999). Combining the analytic hierarchy process and goal programming for global facility location-allocation problem. *International Journal of Production Economics*, Vol.62, 237-248.

Bozdag, C.E., Kahraman, C. & Ruan, D. (2003). Fuzzy group decision making for selection among computer integrated manufacturing systems. *Computers in Industry*, Vol.5, 13-29.

Brezocnik, M, Balic, J. & Brezocnik, Z. (2003). Emergence of intelligence in next-generation manufacturing systems. *Robotics and Computer Integrated Manufacturing*, Vol.19, 55-63.

Buyukozkan, G., Ertay, T., Kahraman, C. & Ruan, D. (2004). Determining the importance weights for the design requirements in the house of quality using the fuzzy analytic network approach. *International Journal of Intelligent Systems,* Vol.19, 443-461.

Byrne, R., Noser, R. & Bates, L. (2009). How Did They Get Here From There? Detecting Changes of Direction in Terrestrial Ranging. *Animal Behaviour*, Vol.77, No.3, 619-631.

Eraslan, E. & Kurt, M. (2007). A Fuzzy Multi-criteria Analysis Approach for Evaluation and Classification of Cognitive Performance Factors in Flexible Manufacturing Systems. *International Journal of Production Research*, Vol.45, No.5, 605-610.

Fekri, R., Aliahmadi, A. & Fathian, M. (2009). Predicting A Model For Agile Npd Process With Fuzzy Cognitive Map: The Case Of Iranian Manufacturing Enterprises. *International Journal of Advanced Manufacturing Technology*, Vol. 41, No.11-12, 1240-1260.

Gras, R., Devaurs, D. & Wozniak, A. (2009). An Individual-Based Evolving Predator-Prey Ecosystem Simulation Using A Fuzzy Cognitive Map As The Behavior Model. *Artıficial Life*, Vol.15, No.4, 423-463.

Hollnagel, E. (2001). Extended cognition and the future of ergonomics. *Theoretical Issues in Ergonomic Science*, Vol.2, No.3, 309-315.

Hossain, S. & Brooks, L. (2008). Fuzzy Cognitive Map Modelling Educational Software Adoption. *Computers & Education*, Vol.51, No.4, 1569-1588.

Kim, D., Han, S., Kim, H. (2009). Structuring The Prediction Model of Project Performance for International Construction Projects: A Comparative Analysis. *Expert Systems With Applications*, Vol.36, No.2, 1961-1971.

Kim, K., Lee, K. & Kwon, O. (2008). The Role Of The Fuzzy Cognitive Map in Hierarchical Semantic Net-Based Assembly Design Decision Making. *International Journal of Computer Integrated Manufacturing*, Vol.21, No.7, 803-824.

Kuo, R.J., Chi, S.C. & Kao, S.S. (2002). A decision support system for selection convenience store location through integration of fuzzy AHP and artificial neural network. *Computer in Industry*, Vol.47, 199-214.

Lang, S.Y.T., Dickinson, J. & Buchal, R.A. (2000). Cognitive factors in distributed design. *Computers in Industry*, Vol.48, 89-98.

Lee, J.W. & Kim, S.H. (2001). An integrated approach for independent information system project selection. *International Journal of Project Management*, Vol.19, 111-118.

Lee, K.C., Lee, N. & Li, H.L. (2009). A Particle Swarm Optimization-Driven Cognitive Map Approach To Analyzing Information Systems Project Risk. *Journal Of The American Society for Information Science and Technology*, Vol.60, No.6, 1208-1221.

Lee, S.J. & Ahn, H.C. (2009). Fuzzy Cognitive Map Based On Structural Equation Modeling For The Design of Controls in Business-To-Consumer E-Commerce Web-Based Systems. *Expert Systems with Applications* Vol.36, No. 7, 10447-10460.

Meade, L.M. & Sarkis, J. (1999). Analyzing organizational project alternatives for agile manufacturing processes: an analytical network approach. *International Journal of Production Research*, Vol.37, 241-261.

Mikhailov, L. & Singh, M.S. (2003). Fuzzy analytic network process and its application to the development of decision support systems. *IEEE Transactions on Systems, Man, and Cybernetics-Part C: Applications and Reviews*, Vol.33, 33-41.

Momoh, J.A. & Zhu, J. (2003). Optimal generation-scheduling based on AHP/ANP. *IEEE Transactions on Systems, Man, and Cybernetics-Part B: Cybernetics*, Vol.33, 531-535.

Morray, N. (1998). Identifying mental models of complex human-machine systems. *International Journal of Industrial Ergonomics*, Vol.22, 293-297.

Niemira, M.P. & Saaty, T.L. (2004). An analytical network process model for financial-crisis forecasting. *International Journal of Forecasting*, Vol.20, 573-587.

Saaty, T.L. & Takizawa, M. (1986). Dependence and independence: from linear hierarchies to nonlinear Networks. *European Journal of Operational Research*, Vol.26, 229-237.

Saaty, T.L. (1996). *Decision Making with Dependence and Feedback: The Analytic Network Process*, RWS Publications, Pittsburgh.

Saaty, T.L. (2006). Rank from comparisons and from ratings in the analytic hierarchy/network process. *European Journal of Operational Research*, Vol.168, 557-570.

Sarkis, J. (2002). A model for strategic supplier selection. *Journal of Supply Chain Management*, Vol.38, 18-28.

Sato, N. & Yamaguchi, Y. (2009). Spatial-Area Selective Retrieval Of Multiple Object-Place Associations in a Hierarchical Cognitive Map Formed By Theta Phase Coding. *Cognitive Neurodynamics*, Vol.3, No.2, 131-140.

Suresh, N.C. & Kaparthi, S. (1992). Flexible automation investments: A synthesis of two multi-objective modeling approaches. *Computers & Industrial Engineering*, Vol.22, 257-272.

Suwingnjo, P., Bititci, U.S. & Carrie, A.S. (2000). Quantitative models for performance measurement system. *International Journal of Production Economics*, Vol.64, 231-241.

Xiaohua, W., Zhenmin, F. (2002). Sustainable development of rural energy and its appraising system in Chine. *Renewable&Sustainable Energy Reviews,* Vol.6, 395-404.

Xirogiannis, G. & Glykas, M. (2007). Intelligent Modeling Of E-Business Maturity. *Expert Systems With Applications*, Vol.32, No.2, 687-702.

Yurdakul, M. (2003). Measuring long-term performance of a manufacturing firm using the analytical network process (ANP) approach. *International Journal of Production Research*, Vol.41, 2501-2529.

Zhang, Q., Vonderembse, M.A. & Lim, J. (2003). Manufacturing flexibility: defining and analyzing relationships among competence, capability, and customer satisfaction. *Journal of Operations Management* , Vol.21, 173-191.

3

System Diagnosis Using Fuzzy Cognitive Maps

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1. Introduction

Fuzzy cognitive maps are an ideal tool for modeling multi-attribute systems, especially when they must incorporate such "soft" parameters as human factors, operator characteristics or societal concepts. Part of the utility of using a fuzzy cognitive map as the primary model of the system under consideration is that it can be constructed by merging submaps, with each submap prepared by a subject matter expert in the topic relevant to it. Piecing these submaps together to generate a complete map of the system often results in unexpected inferences because feedback can become present. Through feedback certain effects may get magnified or mitigated through causal chains that would not exist until the submaps are merged.

A fuzzy cognitive map is a signed digraph that captures the essential cause/effect relationships in a system. (Zhou et al., 2006) The dynamics of the system are captured in the map by its nodal values and the web of directed edges in it indicating a cause/effect relationship. Nodes in the map represent attributes in a system that a subject matter expert believes important in understanding its changes. These nodes must represent changeable quantities, i.e. a characteristic of the attribute that can increase or decrease because the map is primarily a tool for understanding the changes that occur when inputs are perturbed. Nodes are normally assigned numeric values of +1, indicating an increase in the underlying concept, -1 indicating a decrease and 0, indicating no change. Note that the nodal values are crisp in the sense that there is no fuzziness associated with the change in value or its interpretation of the concept represented by it. (Kosko, 1992)

Fuzziness enters the map through the value of the edge strengths. Nodes in the map are connected by a directed edge to indicate that the author of the map believes a causal relationship exists between the two nodes. The edge starts on the causal node and ends on the effect node, with an arrow used to identify the relationship. The edge strengths can be positive or negative. A positive value shows direct causality: an *increase* in Node A causes (results in) an *increase* in Node B. On the other hand, a negative value indicates inverse causality: an *increase* in Node A causes (results in) a *decrease* in Node B. The absence of an edge indicates that no causal relationship is thought to exist. (Kosko, 1987)

Rather than assigning these edge strengths crisp values of +1 (direct causality) or -1 (inverse causality), they are given values on the interval [-1,1] to capture subtleties in the relationships that might exist. Thus, instead of A causes B, degrees of causality can be incorporated in the model that capture partial or imperfect relationships: A somewhat causes B, or A really causes B. As long as a consistent numeric scale is used for the adverbial modifiers, fuzziness in edge strength values can be incorporated. (Perusich & McNeese, 1997)

A fuzzy cognitive map is a true model in the sense that it has predictive capabilities. Sets of nodes can be identified as inputs and act as sources of causality much in the same way a voltage source acts as a source of energy in an electric circuit. These nodal values are applied to the map and allowed to propagate through it until one of two types of equilibrium is reached. In the first, nodes reach steady state values. In the second, termed a limit cycle, sets of nodal values oscillate between two or more values. The process of updating individual nodes is fairly straightforward. The causal values weighted by its corresponding edge strengths are summed and then mapped to the crisp nodal values of +1, 0 and -1 using an appropriate thresholding function. This process is repeated for individual nodes until equilibrium is reached.

Unlike a state machine, it must be remembered that the sequencing through individual values that a node will go through in a fuzzy cognitive map is unimportant. Only the final set of values reached by the map has meaning. The map is meant to model an entire system, with each node representing some control, decision, aspect, condition, or state of that system. It is designed to understand how changes in parts of it affect other parts, with the overall *state* of the system represented by the complete set of nodal values reached at equilibrium.

Just as with any system model, the attributes that capture its behavior can be grouped into three categories: inputs, internal nodes and outputs. Inputs are typically thought of as attributes that are under the control of the user or exist initially when the analysis is conducted. Outputs are usually considered to be attributes and characteristics that result from the environment the system is embedded in, the decisions the user makes and the mechanics of how the system operates. Another important characteristic of both inputs and outputs is that they are externally measurable or controllable from the system. The third attribute, internal nodes, represent the inner workings of the system. These nodes are generally unmeasurable by the user but are useful for developing the model of the system. They provide a structure for the subject matter expert to expound the relationships between the inputs and the outputs.

Fuzzy cognitive maps have two key features that make them ideal for modeling systems that incorporate attributes with multiples characteristics. First a map compares changes of state in attributes to changes of state in attributes so no common numeric scale is necessary in designing it. Because temperature and attitude of an operator, for example, are incorporated in the map by their relative changes, a common scale for measuring them is not necessary. Second, the map, as stated previously, can be constructed from smaller, partial maps through common nodes. These smaller maps are pieced together through the nodes that they share. In this way multiple experts can be used to construct a system map, where each individual expert can put together a submap specific to their domain of expert obviating the need for command language among experts.

Although there are generally a natural set of nodes that can be thought of as inputs, in theory, any set of nodes in the map can be used as such. This gives this technique great flexibility in looking at the system under various conditions. Given this it is often desirable to identify what nodal combinations yield a particular state of the system, i.e. a particular set of output nodal values, i.e. in diagnosing a problem.

2. System diagnosis

System diagnosis is the process of identifying the root causes of a particular effect. In the case of the fuzzy cognitive map this involves identifying which combinations of input nodes can cause (result in) in the outputs under investigation. Diagnosis can be broken in two separate parts. (Tanteno et al., 2006; Perusich, 2007;Kramer & Palowitch, 1987) In the first it is sufficient to identify whether a node or combination of nodes can in fact produce the effect being examined. In complicated maps with potentially hundreds of nodes and thousands of edge connections, this involves identifying whether causal links from input nodes to the output nodes exist. Note that this analysis can be done independent of the values of the nodes and, to some extent, edge strength values. The fact that a link exists is sufficient and will be the subject of this chapter. In the next level of analysis, linked nodes are identified but the strengths of the edges and values of the nodes are used in the diagnosis to give a more thorough understanding of the cause/effect relationships. This type of analysis will be left for future research. (Lee et al., 2003;Pelaez & Bowles, 1995;Pelaez & Bowles, 1996)

The basic process of diagnosis in a fuzzy cognitive map is to produce and manipulate the reachability matrix for the map. (Ndousse & Okuda, 1996) The reachability matrix is built from the adjacency matrix for the map, **J,** which captures the cause/effect relationships in the map. Each row in the adjacency matrix represents a causal node with each column representing an effect node. The adjacency matrix will be NxN, if there are N nodes in the map since each node could in fact be a cause of every other node in it. The value of the element J_{ik} in the adjacency matrix represents the strength of the causal relationship between node i (the cause) and node k (the effect). In other words, the value of the entry J_{ik} is the value of the edge strength from node i to node k. If no relationship exists between the nodes then the entry is 0. Under most circumstances the resulting matrix is sparse with few nonzero entries. Since the intent of the reachability matrix, as opposed to the adjacency matrix, is to determine only whether a causal relationship exists between two nodes and not its strength or path, the adjacency matrix **J** is modified by replacing all nonzero elements with a value of +1. If present fractional and negative entries in J would be given values of +1.

The reachability matrix, **R**, is calculated through repeated matrix multiplication of **J+I**, where **I** is an NxN identity matrix. (Hansen et al., 1978) The maximum multiplications necessary is N, the number of nodes in the map. In practice the matrix multiplication process likely converges well before N multiplications.

$$\mathbf{R}=(\mathbf{J}+\mathbf{I})^{N} \quad (1)$$

A nonzero entry in the reachability matrix indicates that a causal link of unknown path length exists in the between node i (given as a row entry) and node k (given as a column entry).

A simple example can be used to illustrative this process. Consider the 8 node fuzzy cognitive map given in figure 1. The causality in the map comes in several “flavors”. For example, Node 3 is directly caused by Node 1, while Node 4 has an inverse affect on Node 7. Nodes 1 and 3 cause Node 2, but only if both are present; neither alone can cause Node 2. Node 6 is caused directly by Node 2 (inversely) while Nodes 4 and 5 can also cause it, but only if both are present. The adjacency matrix for this map is given as $\mathbf{J_{FCM}}$ in equation 2. As can be seen the matrix is sparse with few nonzero entries reflecting that the map has only 11 causal links.

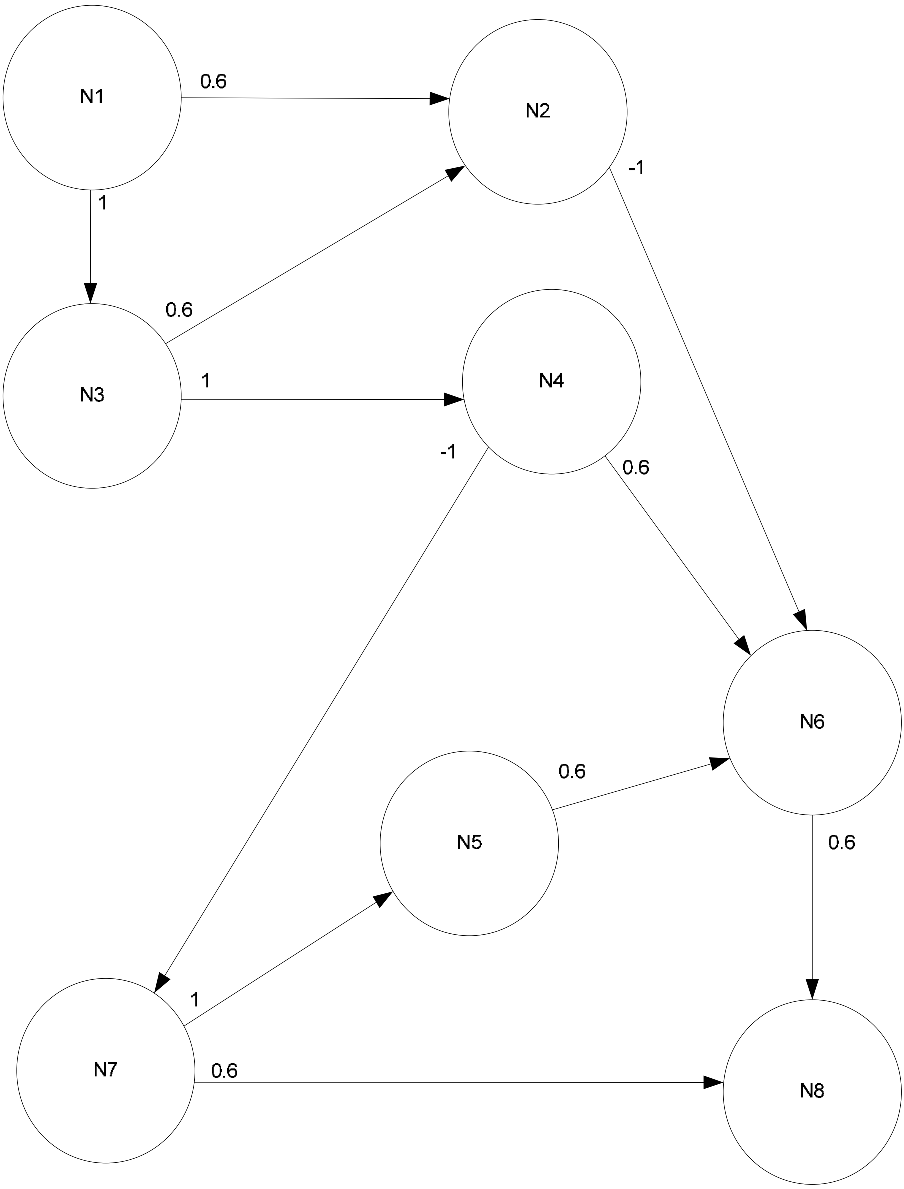

Fig. 1. Example Fuzzy Cognitive Map

To calculate the reachability matrix, $\mathbf{J}_{FCM}$ is first modified by replacing all nonzero entries with a value of 1 to indicate that a causal link exists from the row node to the column node. Once modified this matrix is then used in equation 1 to give the reachability matrix, $\mathbf{R}_{FCM}$, given in equation 3. A nonzero entry in $\mathbf{R}_{FCM}$ indicates that a linkage exists in the map between the causing node (row) and the effect node (column). Note that a nonzero entry indicates only that a linkage is present and gives no information about its path. The causal node may be linked to the effect node through multiple intermediate nodes. For example, the nonzero entry in $\mathbf{R_{FCM}}$ for R_{16} indicates that Node 1 is linked to Node 6 and, thus, can be its cause. The exact path, though, would be through the nodal chain 1-4-6 or 1-2-6.

$$J_{FCM} = \begin{pmatrix} 0 & 0.6 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 \\ 0 & 0.6 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.6 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.6 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.6 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0.6 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \tag{2}$$

The reachability matrix can identify whether a node can affect anther node only. It cannot directly be used to determine the nodal path or paths that link the two nodes, nor can it determine the final strength of the node. Also, it can only identify whether a single node can affect another single node. It cannot identify combinations of nodes that can cause a given effect node, each of which if individually present do not give the result but when present together do. Even with these limitations it is a useful tool for diagnosis. Given that the exact set of inputs in a fuzzy cognitive map is fluid in the sense that in theory any combination can be considered these, using the reachability allows early identification of possible nodes to evaluate and, as important, what nodes to eliminate in the evaluation. These can be compared to the set of known node values and the intersection of the two used as the basis for understanding a failure.

$$R_{FCM} = \begin{pmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix} \tag{3}$$

3. Identification of multiple causes

As described previously the reachability matrix is limited in that it can only identify whether a single node is linked, i.e. causes a given output node. In many cases, though, it is a combination of nodes that is an underlying cause. The following methodology can be used to identify such combinations, but to use the thresholding function that maps the nodal values to +1, 0 and -1 must have certain limitations. If satisfied then the methodology proposed will yield combinations, 2 nodes, 3 nodes, etc. that can be a cause of a given output node.

3.1 The thresholding function

Inference in a fuzzy cognitive map involves the application of a known set of nodal values, the inputs, to the map. These nodal values are held constant and allowed to propagate through the map until it reaches equilibrium. Each node is updated by summing the value of nodes causing it weighted by the edge strength that connects them to it. A thresholding function, **T[]**, then maps the result of the summation to crisp nodal values of +1, 0 and -1. This operation is summarized in equation 4.

$$E_j = T\left[\sum_i W_i C_i\right] \tag{4}$$

where E_j is the value of the effect node, and W_i and C_i are the edge strength and node value respectively of the i node that causes E_j. The summation is done over all nodes that cause E_j. The function T[] maps the value of the resulting summation to one of three value: +1, 0 and -1.
In many instances the edge strength values, W, and the thresholding function, T[], are not entirely independent. Very often the creator of the map will have an idea about which combinations of nodes directly cause a particular single node. The value of W with T in mind is chosen so that the combination selected result in the outcome desired. A simple but powerful approach is to use a simple interval approach for the thresholding function and choose edge strength values that combined fall into the desired interval, but individually do not.
For example, a generalized interval thresholding function would be:

$$\text{if } \sum_i W_i C_i > \alpha \quad \text{then } E_j = +1$$

$$\text{If } -\alpha \le \sum_i W_i C_i \le \alpha \quad \text{then } E_j = 0 \tag{5}$$

$$\text{if } \sum_i W_i C_i < -\alpha \quad \text{then } E_j = -1$$

with α a value in [0,1]. So, if two nodes are to cause a given effect, each edge strength would be given a value less than α but when summed was greater than α. The simplest approach is to choose the same value for each. For example, if α was set at 1 and two nodes were needed to cause an effect then the edge strength values for these nodes could be set at 0.6. If present individually the summation would yield 0.6, less than the threshold value of 1, mapping to E_j =0, but if both were present then the summation would be 1.2, mapping E_j =+1, the desired result.
In general any edge strength value less than α can be chosen to follow the strategy just given, but a useful function is the following:

$$W_i = \frac{\alpha}{n} + \varepsilon \tag{6}$$

where W_i is the edge strength value, α is the threshold value, n is the number of nodes that must be present simultaneously to cause the effect and ε is a scale factor to insure that the sum will exceed the threshold value α. The edge strength values were set in the fuzzy cognitive map in figure 1 using this function with α=1, and ε=0.1. For n=2, i.e. two causing nodes must both be present for the effect to occur, W_i=0.6. There are 3 such combinations in the map where an effect only results if two causing nodes are present: 1,3 yielding 2, with 4,5 yielding 6, and 6,7 yielding 8.

3.2 Identification of multiple causes

To determine combinations of nodes, the adjacency matrix is modified to reflect only connections that meet a threshold value specific to the number of combinations under consideration. Specifically:

$$J_{ik}=0 \qquad \text{if } W_i < \frac{\alpha}{n}$$

$$J_{ik}=1 \qquad \text{if } W_i \geq \frac{\alpha}{n} \tag{7}$$

A modified reachability matrix is then calculated for each value of n:

$$R_n = \left(J_n + I\right)^N \tag{8}$$

where I is the identity matrix, J_n is the modified adjacency matrix using equation 7 and N is the number of nodes in the map. R_n is the reachability matrix for n combination of nodes with R_1 indicating causal nodes that can individually affect the given node, R_2 identifying nodes that individually or in pairs can affect a node, R_3 identifying single nodes, pairs and triples that can affect a node and so on. Note each successive reachability matrix indentifies all previous combinations as well as the current set. To identify only nodes that can cause an effect in pairs, for example, R_1, the reachability matrix for single nodes needs to be subtracted from R_2, the reachability matrix for pairs that also includes single nodes. In general:

$$R_{\bar{n}} = R_n - \sum_{1}^{\bar{n}-1} R_l \tag{9}$$

where $\bar{n}$ is the combination of causes of interest (singles, pairs, triples, etc.). Nonzero entries in a column for $R_{\bar{n}}$ indicate nodes in combinations that are a cause of the effect node represented by the column. If several nodes are indicated then use is map of the map itself to identify which are valid combinations.

Using the example fuzzy cognitive map given in figure 1, R_1 and R_2 can be calculated giving equations 10 and 11 respectively. From R_2 it can be seen that node 2 is caused by the combination of nodes 1 and 2. Examination of the map in figure 1 confirms that these two nodes must occur simultaneously for the effect node 2 to occur.

$$R_1 = \begin{pmatrix} 1 & 0 & 1 & 1 & 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix} \qquad (10)$$

Effect node 6 needs more explanation. From R_2 the matrix indicates that nodes, 1,3,4,5, and 7 occur in pairs to give the effect node 6. Although counterintuitive, examination of the fuzzy cognitive map in figure 1 explains this. As can be seen, nodes 4 and 5 occurring simultaneously will give effect node 6. But node 7 is a direct cause of node 5, so if node 7 occurs, node 5 will occur and in combination with node 4 will yield effect node 6. Likewise node 1 is direct cause of node 3 which is a direct cause of node 4, so if either 1 or 3 occurs node 4 will occur and in combination with node 5 will yield node 6.

$$R_2 = \begin{pmatrix} 0 & 1 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \qquad (11)$$

4. Future research

The methodology given here can only be used to identify linkages among nodes in a fuzzy cognitive map. It cannot assess the importance of a given node identified as a possible cause, only that it might be a cause because a path in the map exists connecting the causing node to the effect node. Even though limited in the information provided it is still useful in screening the nodes for possible causes. The map modeling many complex systems might have hundreds of nodes with thousands of connections. Identifying nodes that are in fact linked to the effect eliminates fruitless searches through the map. Future research should concentrate on techniques that identifying not only whether a linage exists but also give some measure of its strength further narrowing the suspects node in a diagnosis problem.

5. Conclusions

A methodology has been outlined that can be used to identify causal nodes in a fuzzy cognitive map using modified reachability matrices constructed from the adjacency matrix for it. The technique not only identifies direct linkages but can determine combinations of nodes that give the effect nodes of interest. In complex maps with hundreds of nodes this methodology is especially useful because it provides an initial reduction in the set of nodes that must be examined. Once these nodes and combinations of nodes are identified they can be applied to the map to assess which give output nodes of the desired value.

6. References

Hansen, J., Heitger, L., McKell, L., "Computer-aided Modeling of Decision-support Systems", Journal of the Operational Research Society, Vol. 29, No. 8. 1978. pp. 789-802.

Kramer, M. & Palowitch, B., "A Rule-Based Approach to Fault Diagnosis Using the Signed Directed Graph", AIChE Journal, Vol. 33, No. 7. July 1987. Pp. 1067-1078.

Kosko, B, "Adaptive Inference In Fuzzy Knowledge Networks". *IEEE International Conference on Neural Networks*. June. (II-261-268). 1987.

Kosko, B., *Neural Networks and Fuzzy Systems*. Prentice-Hall. Englewood Cliffs, NJ. 1992.

Lee, G., Song, S., & Yoon, E., "Multiple-Fault Diagnosis Based on System Decomposition and Dynamic PLS", Industrial and Engineering Chemistry Research, Vol. 42. 2003. pp. 6145-6154.

Ndousse, T. & Okuda, T., "Computational Intelligence for Distributed Fault Management in Networks Using Fuzzy Cognitive Maps", Proceedings of the 1996 IEEE International Conference on Communications. Vol. 3. 1996. pp. 1558-1562.

Pelaez, C. E., & Bowles, J., "Applying Fuzzy Cognitive-Maps Knowledge-Representation to Failure Modes Effects Analysis", 1995 Proceedings Annual Reliability and Maintainability Symposium. 1995. pp. 450-456.

Pelaez, C. & Bowles, J., "Using Fuzzy Cognitive Maps as a System Model for Failure Modes and Effects Analysis", Intelligent Systems, Vol. 88. 1996. pp. 177-199.

Perusich, K., & McNeese, M. D. "Using fuzzy cognitive maps to define the search space in problem solving.", G. Salvendy, M. Smith, & R. Koubek (Eds.), *Design of Computing Systems: Cognitive Considerations.*, (805-809). Amsterdam, The Netherlands: Elsevier Science Publ. B.V. , 1997.

Perusich, K., Qualitatively Troubleshooting Electronic Circuits using Fuzzy Cognitive Maps. IEEE-EIT2007. Chicago, IL. May 2007.

Tateno, S., Matsuyama, H., & Yoshifumi, T., "Fault Diagnosis Method Using a Signed Digraph for Multiple Origins of Failures-Evaluation of the Diagnosis Accuracy", Proceedings of the 2006 IEEE International Conference on Control Applications, October 4-6, 2006. pp. 3271-3276.

Venkatasubramanian, V., Rengaswamy, R., & Kavuri, S., "A Review of Process Fault Detection and Diagnosis. Part II: Qualitative Models and Search Strategies", Computer and Chemical Engineering, Vol. 27. 2003. pp. 313-326.

Zhou, S., Liu, Z.-Q. & Zhang, J. Y., "Fuzzy Causal Networks: General Model, Inference and Convergence", *IEEE Transactions on Fuzzy Systems*, Vol. 14, No. 3, June 2006. pp. 412-420.

4

Subject-formal Methods Based on Cognitive Maps and the Problem of Risk Due to the Human Factor

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1. Introduction

Recently there appear more and more publications, both theoretical, and applied related to cognitive maps, though with different meanings of "cognitive map" by different authors.
Contemporary cognitive map applications cover different domains: economics, medicine, foreign affairs and others. The spectrum of the problems solved spreads from conceptual modeling aimed to help individual to better structure and understand the problem, up to deriving a shared understanding of the problem, then to most typical simulation of ill-structured situations optionally including their dynamics, and finally to solution of some strategic management problems.
In theoretical studies related to cognitive maps we discriminate two fundamental approaches different in research aims: normative (as people should think) and descriptive (as people do think). Hereby we apply the idea suggested by A. Tversky et al. and presented in the widely known book (Bell et al., 1988) to cognitive map researches.
Followers of the descriptive approach, investigating cognitive processes in people, while decision-making, refer to the concept of cognitive map[1] as the internal model of person's knowledge about some situation[2].
This interpretation to some extent correlates with the definition from Wikipedia[3], though to our opinion it would be more correct to speak about "mental representations composed as a result of a series of psychological transformations" instead of "mental processing composed of a series of psychological transformations".
In the normative approach which applied aim is to suggest people the ways of practical problem solution, cognitive maps of various kinds are proposed as normative models (in other words, as schemes or rules) for external representation of knowledge about situations (whatever the internal representation could be). In this approach the cognitive map of a concrete situation has an external form of structure consisting of elements (named concepts,

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[1] Other terms like mental maps, cognitive models, or mental models are often used as well.
[2] which can be visualized.
[3] http://en.wikipedia.org/wiki/Cognitive_map

factors, or constructs) and, as a rule, causal[4] relations (or links) between these elements and sometimes with some additional attributes (signs, weights of influences).

In cognitive-map-based approach to searching and making decisions, maps with different degree of formalization are used, thus providing the possibility of more or less complicated formal methods application (For an overview see Kuznetsov et al., 2006; Pena et al., 2007; Abramova et al., 2008).

This work is oriented to formal cognitive maps and associated techniques for searching and making decisions in control of complex and ill-structured situations.

There is at least one problem that calls forth involving descriptive approach knowledge into the field of formal models and methods for complex and ill-structured situations (with cognitive maps or not). This is, namely, the problem of risks due to the human factor in this field (Abramova, 2007; Abramova & Kovriga, 2008). First of all the problem lies in the inevitable and substantial humans' participation in solving practical problems with formal methods (at least for formalization of primary representations of a situation), so that it is pertinent to speak about subject-formal instead of formal methods. Due to the humans' participation such methods basically cannot provide validity[5] of ultimate results, or in other words, they are basically risky concerning results validity.

The pragmatic importance of the given problem of risks obviously depends on how much significant are the risks to obtain invalid results in solving practical problems. By present time theoretical, experimental and even practical knowledge has been accumulated, leading to understanding or directly saying that human factors can be a significant source of risk for the results validity (Abramova & Kovriga, 2008). However the importance of the problem in the field of formal decision-making methods is underestimated by scientific community, despite some widely known researches such as the ones on "logic of failure" by D. Dörner (Dorner, 1997) and on psychological correctness in the formal theory of decision-making by O. Larichev and his school (Larichev et al., 1997). (In some more detail see (Abramova, 2007; Abramova & Kovriga, 2008)). This fully concerns the *cognitive-map-based subject-formal methods*.

The problem of human-induced risks in solving practical control problems by means of subject-formal methods and computer-aided technologies (with cognitive mapping being just a special case in the field) is only recently put forward as the complex problem covering the whole life-cycle of such methods and technologies (Abramova, 2007, Abramova & Kovriga, 2008), and it almost has not been explored yet.

In our research of risk factors and ways the human-induced-risk problem might be solved, the interdisciplinary approach is accepted, following the prescriptive approach (in terms of (Bell et al., 1988)) with the idea of integrating normative and descriptive knowledge in decision making but going much further in the scientific knowledge integration with involving relevant knowledge from linguistics, cognitive sciences, sociology, artificial intelligence, computer science, philosophy.

In (Abramova, 2007) a number of principles of protection against human-induced risks at all stages of the subject-formal method life cycle, starting from verification of theoretical

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[4] or, that is the same, cause-effect

[5] Note that validity of results of a method application is understood here in wide intuitive sense as capability to rely upon these results in solving a specific practical problem. It is also possible to speak about validity of a method as its capability to yield valid results.

background and justification of a given method and finishing with verification of formalized expert knowledge and beliefs, have been proposed and is being practically tested (Abramova, 2007). The principles cover various theoretical models of expert knowledge about a problem situation, including formal cognitive maps.

Our principles are well agreed with the known ideas by R. Heuer (Heuer, 1999) about the cognitive challenges intelligence analysts face in the complex information processing, and with his program for "a prudent management system", which, in our terms, proposes verification of analysts' knowledge and reasoning. However, essential difference of our approach consists in focusing on formal methods which can be used by analysts and experts, and not only these people are considered as risk sources, but also theorists, and developers of information technologies and decision-support systems.

In publications concerning cognitive maps (mainly descriptive ones), and also in the adjacent areas one can find some useful information, relevant to the problem of risks due to the human factor using cognitive-map-based methods. Except the works mentioned above (Larichev, 1997; Dorner, 1997; Abramova, 2007), which relation to the problem of risks is briefly described in (Abramova & Kovriga, 2008), the significant results on risk factors and suggested ways of their overcoming can be found in (Heuer, 1999; Hogdkinson et al., 2004; Schaffernicht, 2007).

The present chapter contains: (1) a short survey of contemporary cognitive maps (section 2.1); (2) some ideas relevant to the problem of risks due to the human factor in cognitive-map-based methods (section 2.2); (3) description of two interdisciplinary models, that allow analysis, explanation and forecast of human-induced risk factors in the life cycle of subject-formal methods (section 3); (4) recently discovered human-induced risk factors that reduce validity of cognitive-map based subject-formal methods (section 4); (5) some principles to reducing the risks due to the human factor, and a number of heuristic criteria of validity of use of cognitive maps, applicable for early detection of direct semantic errors and risks of formalization (section 5).

Some of the discovered risks are demonstrated with cognitive maps found in the scientific literature as well as maps that have been used to solve real control problems.

2. Short review of contemporary formal cognitive maps. Some ideas relevant to the problem of human-induced risks in cognitive-map-based methods

In modern practical and theoretical works the concept of «cognitive map» is used more and more in different fields, but it takes various meanings. Often instead of cognitive maps it is spoken about causal maps (Narayanan & Deborah, 2005). Schemes (circles of influence, Ishikava diagrams, strategic maps, etc.) reflecting cause and effect aspects of a business situation while solving strategic planning problems are also referred to as cognitive maps according to some attributes (Bouzdine-Chameeva, 2006). In some works cognitive maps are reckoned among cause and effect schemes where certain logic or mathematical feature of cause and effect relations is reflected (Schaffernicht, 2007), or among conceptual maps with the fixed type of relations (causal) (Huff, 2005 is reflected).

The spectrum of problems in the field of solving ill-structured problems, where it is suggested to use cognitive maps, depends on the kind of maps, and substantially, from the degree of their formalization.

Let us systematize the contemporary cognitive maps and assign the ones of them which are used as the basis for development of subject-formal methods for solving the problems of forecast and control of ill-structured objects and situations.

2.1 Comparative analysis of cognitive maps with regard to formalization degree

In this work the term "cognitive map" refers to the family of semi-formalized[6] and formal models representing the structure of causal (or, that is the same, cause-effect) influences of a mapped ill-structured situation. Among such cognitive maps we can separate *semi-formalized cognitive maps (*Eden et al., 2005; Huff, 2005; Narayanan & Deborah, 2005 for an overview*)*, applied for forming general concept of a situation and analysis (comparison) of person's viewpoints regarding a situation and *formal cognitive maps* applied for analysis and modeling of ill-structured situations on the basis of individuals' beliefs. Formally, the obligatory base of all models is a directed graph, which nodes are associated with elements (short phrase for weak-formal ones and concept, variables or factors for formal map) and arches are interpreted as direct causal influences (or causal relations, connections, links) between factors. Usually the obligatory base is added with some parameters, such as an influence sign ("+" or "-"), including for weak-formal cognitive map, or influence intensity, and some other interpretations for formal cognitive maps both substantial, and mathematical are given to the map. In *semi-formalized maps* there are no any other formalization except graph. At that, the methods of analysis and comparison of the maps on the base of the graph theory are developed.

Among different maps with different degree of formalization, beginning from the fundamental woks by R. Axelrod and F. Roberts (Axelrod, 1976; Roberts, 1976), the one can separate a family of maps which can be appropriately called as *formal maps*. Their distinctive feature are the theoretical models that describe the semantics of this or that map type, that makes them computational (in terms of (Kremer, 1994)) or executable concept-models ((in terms of (Schaffernicht, 2007)) and affords obtaining new knowledge with formal methods (such as simulation, inference).

With regard to the described situations, one can separate static and dynamic cognitive maps. Semantics of the static cognitive maps does not contain time aspect (earlier-later).

To formal cognitive maps correspond to theoretical (general) model which include the formal description of a map, and also obvious or implicit influences aggregation function on the factor. Various interpretations of nodes, arcs and weights on the arcs, as well as various influences aggregation functions onto factors result in various types of theoretical model of cognitive maps (or cognitive map types) and formal means for their analysis.

The general models for different type of maps form schemes of representation of knowledge about concrete situations in the course of formalization. In case when influences aggregation functions onto factors and maps parameters contain the time in an explicit form, such maps will be referred to as maps with strong dynamics. Other cognitive maps will be referred to as the ones with weak dynamics.

The following maps can be referred to the maps with weak dynamics: fuzzy cognitive maps of Cosco (Khan et al., 2004; see the review of maps of this kind in Kuznetsov et al., 2006; Vesa et al., 2007), logic cognitive-map-based on the relational algebra (Axelrod,1976; Chaib-

[6] following of the Kremer's terminology

draa, 2002; Pena, 2007) or other model (Chen, 1995), Wellman probabilistic cognitive maps (see review in Pena, 2007), and others.

The cognitive maps with strong dynamics are classified by the type of the node aggregation function, for example, a linear function is introduced for the maps in the spirit of F. Roberts, a fuzzy function is applied for the dynamic maps in the spirit of Cosco (Silov, 1995; Fedulov, 2005). The concrete map with set of parameters[7] describes not a single situation and not a single dynamic process, but a variety of the processes different in parameters.

To distinguish between current situations and dynamic processes generated by them in the course of modeling, it is accepted to speak about *initial conditions*. Accordingly in the *language of modeling* for description of concrete situations and problems being solved we may separate the *language of cognitive maps* and *language of initial conditions* so the concrete cognitive map together with initial conditions sets model of a concrete situation.

Let us consider in detail the cognitive maps in the spirit of Roberts, that form a family of general models of cognitive maps with strong dynamics with base linear impact model, offered by Roberts for the sign and weighed graphs (corresponding to maps) for solving the problems of forecasting of complex system behavior. (Roberts, 1976).[8] For such maps the type of the aggregation function for causal and externally conditioned influences on factor x_i is defined as follows:

$$x_i(t+1) = x_i(t) + \sum_{j \in I_i} a_{ij}\left(x_j(t) - x_j(t-1)\right) + g_i(t), \quad i = 1,\dots,N \qquad (1)$$

where $x_i(t+1)$ and $x_i(t)$ are the values of i-th factor at instants t+1 and t, respectively, $x_j(t) - x_j(t-1) = \Delta x_j(t)$ is the increment of factor x_j, a_{ij} is the weight of factor x_j influence onto factor x_i, I_i is the set of factors directly effecting factor x_i; $g_i(t)$ - external influence at instant t.

Cognitive maps of this type differ with regard to modifications of the base model. Weight anyhow formally is represented in all such maps, for example, by number or linguistic value of type "strongly (poorly) influences" which is automatically converted into number.

In a number of works the base model (1) is projected onto the maps, representable by the functional graph[10]. On the base of such maps there are developed various methods and approaches (Kulba et al., 2004; Gorelova, 2006) that support searching solution in control of ill-structured situations, in particular, the methodology for deriving scenarios of ill-structured system that allows carrying out research of its behavior for various control actions. It should be noted that some researchers (Kulba et al., 2004) working with the such models do not use the concept of cognitive map for complex situations model.

One more widely used modification of the maps in the spirit of F. Roberts is the model of cognitive maps of E. K. Kornoushenko and V. I. Maximov[11] with values of factors and

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[7] i.e., dynamic system from the formal point of view.

[8] Generally speaking, the basic results have been received for sign graphs, and inclusion of weights was considered as model development.

[9] In base model the concept variable, instead of factor is used.

[10] In the specific case, a real number (then it is a weighed graph).

[11] Hereinafter referred to as *Kornoushenko-Maximov cognitive maps*.

relations from the interval [-1, 1] (Avdeeva & Kovriga, 2008; Avdeeva et al., 2007; Kornoushenko & Maksimov, 2001)[12]. This research team uses linguistic variables, which automatically converted to numbers. Another particularity of theoretical model of *Kornoushenko-Maximov cognitive maps* is the "compulsory" stabilization by proportional change of the map weights (Maximov & Kornoushenko, 2001). This research group has developed the following subject-formal methods and corresponding information technologies: method of structure and goal analysis of ill-structured system development; approach to studying conflict situations generated by contradictions in interests of subjects influencing development of considered system; approach and methods for solving ill-structured problems and deriving scenarios of ill-structured system development.

The formal cognitive maps and the subject-formal methods on their basis are the ground for construction of practical situations models, and then the criterion of the map adequacy is the situation under investigation. It determines the need for taking into account the problem of risks relating mainly to the distortions in formalization of person's initial knowledge.

2.2 Some ideas relevant to the problem of risks due to the human factor in cognitive-map-based methods

Among some representatives of the descriptive approach who investigate how professional analysts and beginners think (without necessary direct relation to cognitive maps), the one will notice the interest to the questions of validity of knowledge representation and problem solving for complex situations.

On the contrary, the community of the scientists in the field of formal decision-making theories and specialists implementing formal methods in information technologies, as a rule, rely on common sense regarding representations of the ways the person should think (including both knowledge representation schemes and the order of their filling).

Among few works in the field of cognitive mapping, with recognizing not only the human factor influence, but also necessity of researches in this direction, it is worthwhile to note (Bouzdine-Chameeva, 2006), where validity of cognitive maps with internal validity between the data and the conceptualization of the data, including the definitions of concepts and influences, has been discussed, proceeding from the general ideas of content-analysis reliability. The analysis of publications relevant to the problem of risk has been directed mainly on revealing factors, significant for working out subject-formal methods protected from invalidity of final results.

In the field related to cognitive maps the closest to this topic is the experimental research by G. Hodgkinson at al. (Hodgkinson et al.,2004). It is devoted to rigorous evaluating the relative merits of the alternative knowledge elicitation procedures in causal mapping. In the context of the problem of risks, this research draws attention to the experimentally confirmed fact of essential dependence of resulting maps on the elicitation method (in the experiment, pairwise comparisons technique versus freehand drawing). It is argued that all mapping techniques involve recall and recognition processes to different extents, up to some elements being constructed “online”. In that, distortions (in our terms), caused by a map-elicitation-method may have not only more or less negative character (due to recall and recognition errors), but also may develop creative insights.

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[12] Such modification makes a map nonlinear.

R. Heuer (Heuer,1999) considers cognitive biases in analysts' judgments and solutions, i.e. mental errors caused by simplified information processing strategies, those being similar to optical illusions in that the error remains compelling even when one is fully aware of its nature. He marks out biases in perception of cause and effect which may be significant at cognitive mapping. (For example, analysts often perceive relationships that do not in fact exist via illusory correlations or tend to assume that economic events have primarily economic causes.)

In (Richardson, 1997) it is shown that in word-and-arrow diagrams with positive and negative signs on links (including dynamic cognitive maps) link is semantically double-meaning: it can be interpreted both as proportional and additive influence, with the latter meaning for the accumulating nature of rate-to-level link. According to Richardson, the double-meaning in specific situations can be resolved if the modeler knows the meanings of the concepts in the diagram and thus knows necessary meaning of the link. However, as Shafferniht showed in his work with students, people are inclined to simplify the understanding of polarity of influences, and find difficulty in distinction of different kinds of dynamic causal influences, using the simplified ("popular") interpretation of polarity. Moreover, to the above godsends we can add that in formal dynamic maps, such as maps in the spirit of Roberts, the identical semantics of all influences usually proportional or close to it, is implied so indistinct human understanding of influences is meant.

Below (in section 3.1) we show that the discovered problems can be taken into account while analyzing the risks in application of various cognitive-map-based methods.

The question "what should be done" in regard with the discovered difficulties has one of the answers in essence that consists in development of training methods that take into account the cognitive peculiarity of adults and beginners. The most radical answer is given in the program of R. Heuer (Heuer, 1999). This program assumes, for the purpose of increasing the validity of results of intellectual analysis in the complex information processing, the whole complex of long-term measures, including, financial and organizational ones, and a number of mental techniques, some of which are applicable in cognitive mapping, including application of formal cognitive maps. In our terms, he offers verification of analysts' knowledge and reasoning.

3. Analysis, explanation, and forecasting of risks: models and approaches

3.1 The general model of computer-aided decision making

The present section describes the simplified model of the decision making process by means of computer-aided subject-formal method for ill-structured problem situations. The purpose of this model is to describe and explain one general risk occurring mechanism when using such methods in practical decision-making. The model is also applicable as a prototype to analyze the risks due to the human factor in more complicated decision-making processes.

The model represents a decision-making process as search for a solution of a problem situation that consists of 3 stages: 1) forming and formalization of representations and beliefs about the situation which is carried out by decision-maker or decision-making personnel and finishes by entering a formalized situation model into the computer; 2) generation of new formal knowledge about the way the problem situation may be resolved by processing entered information in the computer (analysis, forecasting, search and justification of decisions, etc.); 3) digestion of new knowledge by decision-making personnel to be used to control the situation. The first stage is sometimes interpreted by information technology developers as expert knowledge elicitation or acquisition.

From the point of view of human induced risk analysis, such a process of the new human knowledge generation is interpreted as a process of initial (internal) person's knowledge generation and its cognitive transformations into the final result which depends on the way of knowledge formal representation in the computer.
The model of the cognitive knowledge transformation process is presented in fig. 1.

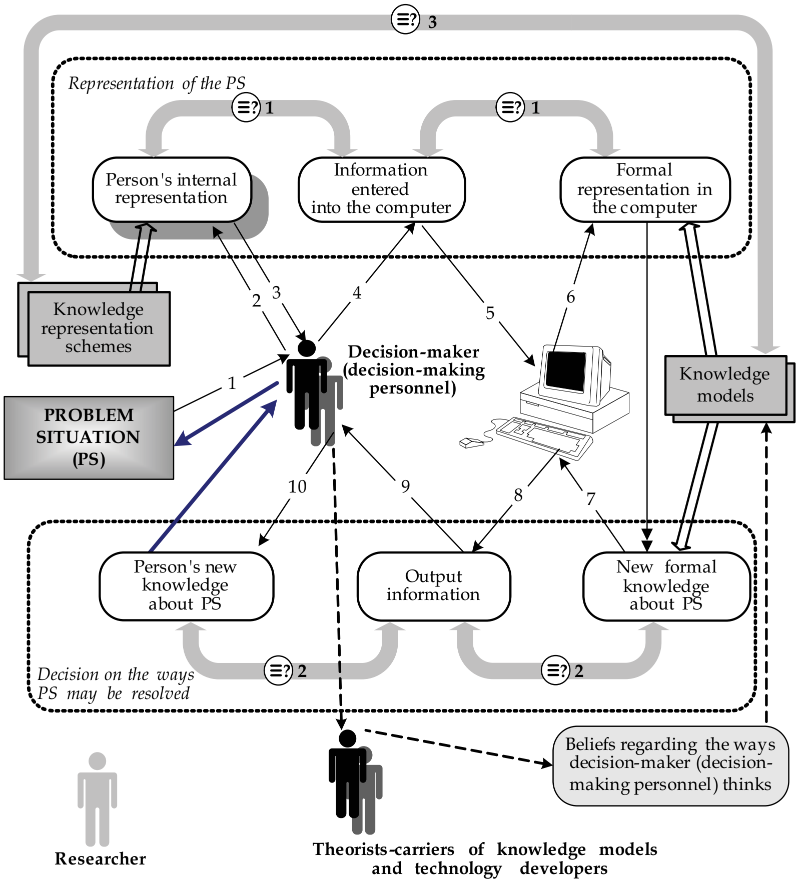

Fig. 1. Model of cognitive transformations while searching and making decision in ill-structured problem situation

The model is simplified: in particular, a single decision-maker is considered, so everything concerned the matching of different people's representations and beliefs are omitted; the structure of the process is simplified as much as possible.
Methodologically the transformations are represented in the spirit of V. Lefebvre (Abramova et al., 2009) as reflections of a real-world situation and others' representations about the situation in the person's mind.
In the model in fig. 1, the problem situation is primarily reflected in the person's mind and as a result his internal representation about the situation is formed (it is shown by thin arrows 1 and 2). Then the formalization step, i.e. the secondary reflection takes place, and it finishes with entering the information into the computer (arrows 3 and 4). This information changes its carrier and is being filled with the meaning once again, thus it becomes

knowledge of "the formal expert", that is the computer (arrows 5 and 6). (Certainly, in a strict sense, the computer only processes the information, however it can be considered as meaningful due to adding a formal sense according to which it is formally processed further.) New formal knowledge about the problem situation and the ways it may be resolved is generated by the computer (double end arrow), and undergoes a similar chain of transformations in a reverse order (arrows 7, 8, 9, 10). As a result the new knowledge is comprehended by the decision-maker, "fitted" to his initial knowledge, and, if acceptable, can be used to influence the problem situation (bold arrows in fig. 1).

The described model of knowledge transformations is in whole (to within simplifications) applicable for a special case of subject-formal cognitive-map-based methods.

When analyzing the above process with risks in view (fig.1), it is necessary to answer the question whether it is possible to consider primary reflection of the initial situation (arrows 1, 2) and transformations of knowledge "about the same" (arrows 3…6) as acceptable in respect to validity of final results. The similar questions stand for transformations of the results (arrows 7…10). (In fig. 1 these questions are presented as questions of identity of the corresponding representations, marked as "≡?1" and "≡?2"). In other words, the question is about adequacy or at least acceptability of reflections of knowledge "about the same", from the point of view of the researcher supposed to be objective and informed.

In our early works based on theoretical considerations in various domains of scientific knowledge including philosophy, linguistics, psychology, artificial intelligence, *the principle of the distorting effect* was put forward that affords to characterize the considered objective processes of reflections with the following theses.

1. Reflection of various objects in the person's mind, in general, happens with distortion.
2. The inevitable source of distortion in the person's reflected knowledge is the person himself with his internal cognitive means.
3. Knowledge transfer between persons, in general, occurs with distortion.

The studies show that as to consequences, distorting effects in knowledge can be considerable and not considerable, positive and negative, acceptable and not acceptable; positive effects promote achieving goals, negative ones prevent it or at least become risk factors.

Let us briefly describe the basic person's cognitive means at primary reflection of a problem situation and the subsequent formalization. It is assumed that the basic person's means at primary reflection are the internal knowledge representation schemes, inherent in a person and frequently unconscious, as well as the general concepts which are jointly structuring his internal knowledge and beliefs about a problem situation.

It is important to underline that in the model there is no assumptions about the structure of internal representations (in the spirit of cognitive map definition from Wikipedia[13]), beyond the assumption of dependence on internal cognitive means

At the formalization stage the basic cognitive means are theoretical models of knowledge of the situation and so-called *interface concepts* of computer technologies (Abramova, 2002), which are usually a component of the above models. These concepts are used to elicit formalized knowledge from problem area experts and to interpret the results generated by computer.

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[13] http://en.wikipedia.org/wiki/Cognitive_map

In the case of cognitive mapping with formal maps we, first of all, mean theoretical models of some or other type of maps, models of interaction with the environment, initial conditions to distinguish a current situation in the set of situations described by the given map. The basic interface concepts are *the factor* (or *variable*), *influence* (or link, relation), *influence weight* (or *intensity*).

According to the distorting effect principle, both these means and their change in the course of knowledge transformations, become the risk factors. When the computer joins the process of knowledge transformation as "the formal expert", there arises a situation of change of knowledge carriers with their different interpretation of knowledge represented according to "the same" schemes with the distorting effect between different representations.

For example, in spite of all seemed strangeness to ordinary thinking, at cognitive mapping the vagueness of the concept of the influence weight as well as ignoring the fact that in mathematical sense weights in a map characterize not only separate influences, but also proportions of different influences onto one factor, become significant risk factors for final result validity, along with known facts of cognitive biases in weight estimation. In some more detail the means and mechanisms of distortions are analyzed in (Abramova et al., 2009).

In terms of the model of knowledge transformations, the question about risks is whether it is possible to assume that cognitive means which are subconsciously used by a person when comprehending (primarily reflecting) a problem situation and subsequently formalizing the initial representations about it are identical with the formalized models of knowledge about a situation. (In fig.1 this question is marked as "≡?3"). More exactly, obviously assuming the distinctions in above cognitive means, the question is, whether it is possible to consider the distorting effect brought by these distinctions, insignificant or, at least, acceptable.

According to the model considered, the distorting effect at change of cognitive knowledge representation means for "the same" knowledge is accepted as the basic mechanism of risk, so we can speak about cognitive risks in the course of transformations.

Note that formal transformation generating new knowledge about a problem situation from the entered knowledge (double-end arrow in fig.1) also could be considered as the risk factor for final result validity. However, today the theorists of formal science believe that formal methods are verifiable so it is not worthwhile to treat such situation as typical one. In section 3.2 we show the example disproving this belief with a distorting effect mechanism.

Stemming from the presented simplified model of cognitive knowledge transformations at decision-making in ill-structured problem situations, the analysis of human-induced risks for a specific technology and its decision-support system should include two stages of analysis: at the "macro-level" and at the "micro-level". At the macro-level the technological approach is required where the process of the new knowledge generation is described as the structured (according to the technology) collective activity. This activity participants and knowledge carriers are people and "formal experts"- computers, and both act according to the roles prescribed and tasks to be fulfilled. At the micro-level, the analysis of effects of psychological and other factors and mechanisms in the described process which can result in significant risks for final result validity should be carried out.

Our practice shows that this general methodology in whole is applicable to the cognitive-map-based methods, though further researches aimed at systematization of risk factors and their practical significance are required.

3.2 Model of cognitive control at formalization. Two kinds of risk factors

Let us consider in brief the further development of the above ideas in (Abramova, 2002) concerning the stage of formalization. Fig. 2 visualizes the model from (Abramova, 2006) which treats the change of subject's cognitive means of knowledge representation at the stage of formalization as action of the imposed forms of thinking and interprets such action as the cognitive control. In the above model of cognitive transformations the subject is a decision-maker.

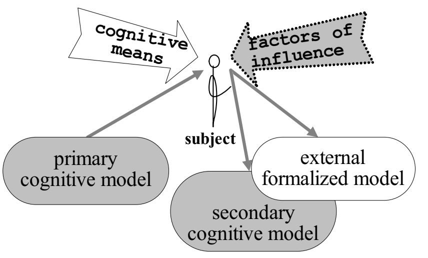

Fig. 2. Formalization of the subject's representations about a situation under cognitive control

The concept *control* is used in the sense accepted in the control science as a purposeful influence on the object of control; here a decision-maker turns to be the object of control. The purpose is formalization of primary knowledge about a problem situation in order to apply a formal method for new knowledge generation. Cognitive control means that control acts upon subjective cognitive means of the person interpreting a situation; first of all, these are his (or her) general concepts and knowledge representation schemes in terms of which the formalization of the person's internal representation of the situation occurs.

The internal representation of a situation is considered as the cognitive model of this situation. It is a model relative to a situation as well as any reflection in the mind of the person, and it is cognitive one as been formed with cognitive means. In the process in fig.1 cognitive control is carried out with imposing the prescribed cognitive means upon the expert at the formalization stage (i.e. expert knowledge elicitation), starting with means of structuring a situation: general concepts and theoretical models as schemes to formally represent knowledge about a situation. The example of such general concepts for cognitive-map-based formalization is given below.

In comparison with the above model of knowledge transformations (Fig. 1) the given model has one essential refinement. It is not only the external formalized model (the input information for a computer and/or the document if stipulated) that is treated as a result of the initial cognitive model formalization, but also the change in the state of an internal model of a situation leading to a secondary internal cognitive model. Such a concretization is essential in the design of computer support to formalization processes with taking account of distorting effects and planning protection against risks.

According to the principle of distorting effect, it is assumed that in generally all three models (fig.2) only more or less agree with each other. (In a specific case the effect can be unessential in the context of a solved problem.) Here it is possible to see deep analogy to the known relativity hypothesis of Sapir-Whorf telling that the picture of the world depends on a natural language, with the difference that the language means for structuring analyzed situations are over imposed onto natural ones.

The problem of the form and extent of discrepancy of the new situation models from the initial one is decisive for an adequate solution of practical problems. It is easy to admit that in a specific situation the result can depend not only on the means of formalization acting upon the subject, but also from himself and others' influences, besides imposed formalization means. Theoretical considerations, the analysis of practice and known facts of essential negative distorting effect have led to necessity to consider psychological factors of influence on the result and its correspondence to acceptability norms for practical problems under solution. In this context the major pragmatic problem consists in how to structure diversity of known factors with the purpose to identify relevant sources of risk factors and search for protecting means. To cope with arising questions, we consider two kinds of risk factors (Abramova, 2006).

The risk factors psychologically influencing validity of expert (or subject-formal) methods during their application by experts and analysts are referred to as first kind factors, or factors of direct action. Such factors can either objectively promote invalidity of results, or raise subjective confidence of experts of objective validity of the method application results. One can tell that they represent themselves as factors of belief. Conductors of these factors influence are experts and analysts; just they appear in conditions which may lead, eventually, to insufficiently valid (in the objective ration) results.

Second kind risk factors or factors of indirect action psychologically influence upon validity of subject-formal methods during their creation and substantiation. Conductors of influence of such factors are creators of methods, scientists and experts producing standards who, in turn, are subject to influence of scientific norms, paradigms, etc. At presence of second kind factors at the stage of formalization of primary representations first kind factors can be induced by action of second kind factors on experts and analysts.

In some cases the imposed forms and thinking stereotypes are not identified obviously so pertinently to speak about influence of ambient intelligence and myths. The interaction of cognitive means of knowledge formalization and other factors of influence which lead to cognitive biases are presented in fig. 3.

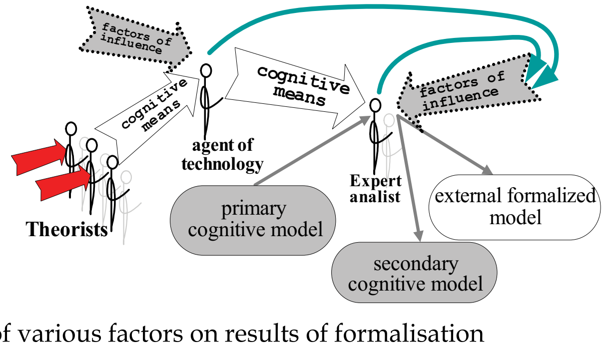

Fig. 3. Interaction of various factors on results of formalisation

As an example, one type of risk sources can be given, those acting regularly at the formalization stage, in particular, for cognitive-map-based methods. These are "two-faced" concepts (Abramova et al., 1999) that are usually entered as the interface concepts for elicitation of knowledge from experts and analysts (arrows 3,4 in fig.1). Such a concept has two "faces" that is two meanings turned to different people: a practical meaning for carriers of knowledge about problem situations and scientific one for carriers of scientific knowledge as well as information technology designers who try to convert more or less strict and sometimes complex scientific concepts into the "intuitively clear" language of vague natural concepts.

A widely known example of such a concept which can create the significant distorting effect at the stage of formalization, is concept "linguistic variable" with verbal values represented in the computer on the numerical scale. This standard transformation (arrows 5, in fig.1) is put into a number of cognitive-map-based methods. It adds equality of distances between adjacent values to the ordering relation of verbal values, which the person means in his estimations (considerable distortion of initial meaning). With such formalization which does not take into account the specificity of subjective (personal) scales in specific situations, it may appear, for example, that a "low" (below average) man or house will be twice lower than "enough high" (above an average) one.

The transformation of scales is based on intuitive belief that "it's all the same" (identity 1 in fig.1), fixed in the scientific stereotype which makes this transformation a professional norm. The attempts to uncover the roots of this stereotype show that theorists and technology developers form in their mind some or other universal linguistic scale that does not depend on the context and the person. Such an ordinal scale admits formal transformations into the proportional numerical scale. Nevertheless it is intuitively clear from examples as well as experimentally proved that this induces essential distortions of expert knowledge. This idea of the way the decision-making personnel think when estimates weights, supported with the stereotype, turns to be the second kind risk factor. This second kind factor operates quite often with distorting the expert knowledge unnoticeably for its carriers (experts).

As the example shows, one of ways for revealing of second kind risk factors is checking the reasoning of knowledge transformations in transitions between formal knowledge of the computer and knowledge of people (Abramova, 2007; Abramova et al., 1999).

4. Recently discovered risk factors due to the human-factor in cognitive-map-based subject-formal methods

The proposed models and approaches for analysis, explanation, and forecasting of risks allow to systematize to some extent risks due to the human factor which, ultimately, can lower validity of subject-formal methods on the basis of cognitive maps with regard to: the place in the process of cognitive transformations of knowledge; the place in method life cycle; the human roles in this cycle. However, it is already clear, that even the set of risk factors discovered by now, makes a rather difficult cause and effect structure[14].

To date our researches give considerable attention to two recently discovered problems (Abramova & Kovriga, 2008; Abramova et al., 2009) which are caused by second kind risk factors. The first one is the problem of false transitivity of causal influences; and the second one is the problem of vagueness of semantics of general models and modelling languages when solving practical tasks by means of formal cognitive maps. The problem of false transitivity and the risks related are considered in section 5 together with its possible solutions. The problem of semantics vagueness is considered in the given section with emphasis on the analysis of its mechanisms and their causal relations.

The object of analysis carried out is modeling of situations by means of dynamic cognitive maps in the spirit of Roberts. Its results are briefly presented on a Fig. 4 in the form of ill-formalized cognitive map of risk factors relations, where all causal influences have identical content "increases" risk.

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[14] In (Abramova et al., 2009) we have tried to present knowledge on some known risk.

Let us define some concepts more concretely. General and concrete situation models appear in definitions of factors in the map on fig. 4.

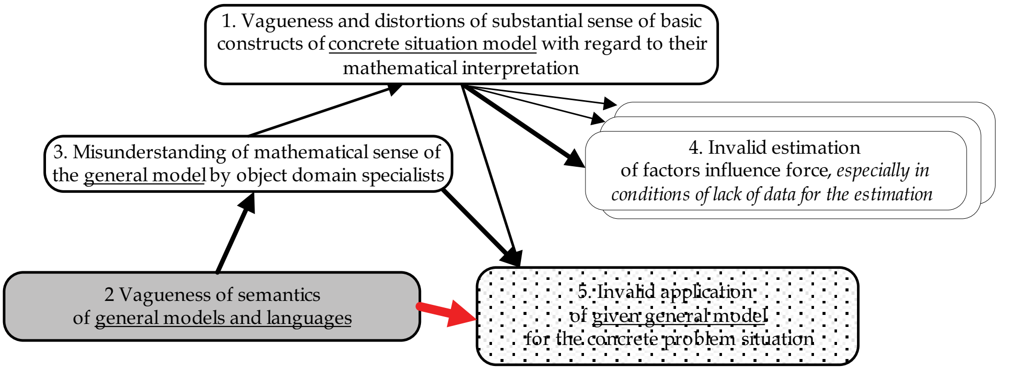

Fig. 4. Analysis of influence of models and languages semantics vagueness on the risks of invalid solution of problems by means of dynamic maps in Roberts' spirit

According to what has been said in section 2, it is supposed that general models for different type of maps form schemes of representation of knowledge about concrete situations at the stage of formalization, or in other words, languages for representation of such knowledge[15]. Concrete model of a situation is a result of formalization which is entered into the computer. In languages of situations modeling on the base of formal dynamic maps in the spirit of Roberts elementary constructs in situation description are factors, direct causal relations between them and weights of influences attributed to relations, which in aggregate form a cognitive map, in the combination with initial conditions which are attributed to factors.

Semantics of the certain modeling language is defined by basic constructs which, besides the named elementary constructs, include "node": the factor with all incoming direct influences together with the function of aggregation of (direct) these influences.

When analyzing the influences of the risk factor 2 we mean that the vagueness in all factors of the risk map (Fig. 4) may appear in the form of ambiguity of understanding and\or derived results between different people or even one person. Influences of the factor 2 can go through the chain 2→3→1 to 4 and to other risk factors concerning different constructs defining semantics, which are not shown on Fig. 4.

Let us track, for example, the origination of risk through the typical chain 2→3→1→4. The intuitive metaphorical concept "influence weight", or its analogue "influence strength" which is used in all investigated type of maps in the spirit of Roberts, is vague in substantial sense: the expert is free to chose any of heuristic techniques for weighting particular influences when the valuation scale is given.

The mathematical sense of weight is specified by influences aggregation function, accepted in a certain theoretical model. In Roberts's base function (1) and its known modifications the weight of influences in aggregate reflect the proportions of separate influences. It means that

[15] In more strict terms of formal languages theory, the general model, as a rule, defines language semantics, and the language implements this model detailing semantics and syntax.

estimation of weights is expedient within the context of other influences. However due to the vagueness of representation of weight semantics to experts - language users they may not know or not realize or underestimate the mathematical sense of weight, and it activates the chain 1 →→ 4. Some available heuristic explanations of estimation of weights for real maps show that the specific character of mathematical sense of weights is ignored. Moreover, the known modern technologies of decision support on the base of formal dynamic maps in the spirit of Roberts make no provision for consideration of any context.

One more kind of risk, presented by the factor 5, is activated in conditions when decisions on applicability of given general model of cognitive maps and associated subject-formal method should be made. This decision should be made on the basis of knowledge of the problem situation specialists a priori, i.e. prior to the formalization stage, but it can be changed in the course of formalization if irrelevances are revealed.

However in the presence of factor 1, there is a risk that invalidity of the given model and the problem solving method with regard to a concrete situation will remain unnoticed nor a priori (the chain of influences 2→3→5), neither during formalization (the chain of influences 2→3→1→5). Some examples of such kind, when the one should refuse from application of the given model if there are no valid means to describe the situation by the given language, are presented in section 5.

Let us consider another, more nontrivial example of results of influence of semantics vagueness of models and languages on risks of invalid problem solving in some known information technologies which realize modeling of cognitive maps in the spirit of Roberts. In this case the risk consisted in inadequate application of the general model to a concrete modelled situation (factor 5 on Fig. 4).

The vagueness of modeling language semantics in this case appears in the latent ambiguity of the concept *initial condition* which is non-terminal concept of this language. The mathematical concept "initial condition for the factor x" in the meaning that is usually used for dynamic maps in the spirit of Roberts, is the number that expresses remainder Δx (0) (according to the formula 1or similar formulae). From the point of view of dynamics, this concept has, at least two considerably different by kinds of the factor dynamics meanings (, according to the two graphically presented on Fig. 5).

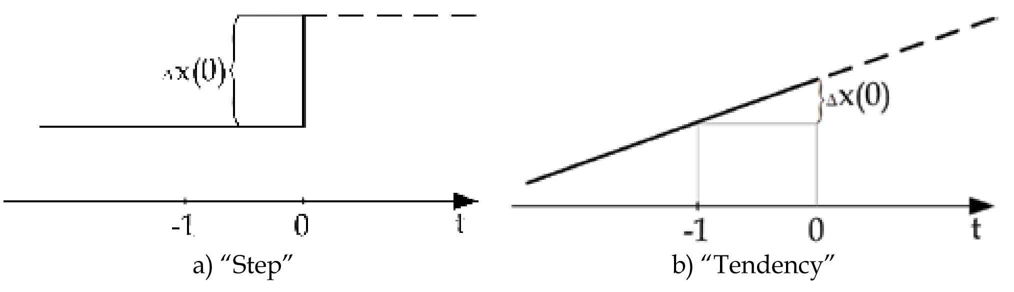

Fig. 5. Two typical kinds of dynamics of cognitive map factors

The first one (Fig. 5a) is named *step*, or, in Roberts's terms, *impulse* which occurs at the moment of time modeling starts t =0. The number Δx (0) expresses the step size. The second meaning matches in substantial sense with interpretation "tendency" and characterizes the dynamics when the speed of change of the variable remains constant, at least, on the average during some time, including the interval (-1, 0), and, probably, will remain constant, if there would be no reasons for its change (Fig. 5b). The number Δx (0) expresses this speed.

The first meaning corresponds to the verbal templates expressing initial conditions of type "factor x has strongly (or is weakly, moderately, …) increased (or decreased)", and the second meaning - to the templates of type "factor x is strongly (or weakly, moderately, …) increasing (or decreasing)".
Essentially, the choice of one of these two semantic meanings for representation of observable dynamics of factors leads to different models of behaviour (indiscernible within the frameworks of existing vagueness) and to different applied statements of modeling problems. Thus, if one of the models is applicable to the concrete situation, for applied reasons, the second one is not.
In the aforementioned technologies, where the considered risk was actualized, the widely known modeling technique coming from Roberts is applied [Section 2]. This technique allows to define the cumulative effect from simultaneous steps in all or in the part of factors, in the course of the transient process (if the one is stabilized). However for representation of initial conditions and results the users are being actually offered another model – in the form of verbal templates of the second kind or even with obvious implementation of the term *tendency* into the dialogue. Thus the technology actually realizes the following chain of transformations: *initial tendencies ⇒ initial steps → steps processing → cumulative change of values ⇒ new tendencies*, including the change of substantial sense of the initial data on dynamics of factors of a map and the results of modeling, while exchanging data between the person and the computer. Thereby the method of modelling of results of impulse (spasmodic) change in dynamics of a situation is applied to *situations of self-development*, where the steps, but not tendencies take place.
The nontriviality of the situation considered is that the risk was actualized only via the factors of the second kind, escaping the experts and analysts (direct influence 2→5 on Fig. 4).

5. Some principles of cognitive mapping validity increase

For cognitive mapping validity increase we put forward a number of principles. The principles include the following.

a. Accumulating experience of typical errors and risk factors.
b. Early detection and blocking of risk sources and semantic errors of formalization not putting obstacles in the way of further application of a chosen type of a cognitive map and a map-based method. Protection and blocking of risk sources is provided by adjustment of formalized knowledge with control of risks.
c. The chosen type of cognitive map applicability walkthrough for particular situation, including a priori and a posteriori control.

The proposed principles are directed to development of the following methods and supporting informational technologies: cognitive mapping by expert and verification of the cognitive maps.
Analysis of risks due to the human factor discovered by now (see Section 4) indicates advisability of statement and research of verification problem for modelling on the base of cognitive maps (see Section 5.1).
The questions of formalization validity criteria for realization of aforementioned principles also are still open. At that, the criteria applicable at early stages, i.e. until formal processing of formal model of experts' initial knowledge, are of special interest.

We propose a number of validity criteria for formalization of expert knowledge by means of cognitive maps intended for more effective detection of direct errors and risks for validity of formalization results (see Section 5.2).

The criteria are local, i.e. these are applied to single constructions of a cognitive map of a situation. The locality property simplifies and systematizes the process of their application by both experts compiling cognitive maps and verifiers carrying out control of formalization correctness.

5.1 Problems and principles to verification of cognitive maps and models

Taking into account the risks discovered (Section 4), we distinguish two verification problems:

a. Verification of well-known formal cognitive map models.
b. Verification of cognitive-map-based situation models while solving real-world problems.

We develop a verification approach relying on experience of practical software verification. At that, this approach has a specific feature: verification is considered, in the first place, as a human activity, and formal methods are the means supporting such activity. The validity criteria system in general case is predetermined only partly and can be extended by experts in the course of particular verification[16]. As it is proved by practice and experiments, just this approach turns to be effective for modelling of problem situations on the base of cognitive maps.

Verification of general cognitive-map models. The principle of verification of modelling language semantics for ill-structured situations on the base of cognitive maps according to criterion of clarity of general theoretical models was proposed within the framework of verification problem for general theoretical models on the base of cognitive maps (Abramova, 2007). This is conditioned by selection of vagueness of models and languages for formalization of initial expert knowledge as a practically significant risk factor. This vagueness results in the ambiguity of interpretation of the general model. This is also confirmed experimentally. We propose a technique for verification based on developed earlier approach to formalization of description of different theoretical models of functional scheme types (Abramova, 1993). The technique has passed partial examination for some types of cognitive maps based models. As a result, we have discovered vagueness of semantics of several well-known theoretical models of cognitive maps and have carried out correction with "splitting" these models to alternative variants with significant difference in their properties and correct problem statements for forecast of dynamics of analyzed objects and situations.

Verification of particular cognitive maps that are built while solving real-world problems of modelling and control is aimed at:

- recognition of risky local fragments of formal model under construction and direct semantic errors of formalization;
- early control of applicability of the chosen type of general model of cognitive maps via correction of a priori estimations (assumptions) of its applicability to a particular situation in course of formalization.

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[16] in psychological terms, cognitive control of experts works

Further research is directed to development and empirical testing of methods for verification of general and particular cognitive maps taking into account known (discovered before) factors of risk due to the human factor for validity, to their application to informational (cognitive) technologies of decision making support.

5.2 Some criteria of cognitive maps validity

To reduce the risks due to the human factor, we propose and ground a number of heuristic criteria of formalization validity that can be applied for early detection of direct semantic errors and risks of formalization. These criteria can be applied both at the stage of model construction and stage of verification.

All criteria that we obtained form the following two groups:

- Criteria that can be applied to individual formalization.
- Criteria of collective knowledge conformity.

These criteria were formulated mainly as applied to the cognitive maps in the spirit Roberts (see Section 2.1). However, degree of generality of the proposed criteria allows to expect applicability to other cognitive map types.

Here we consider some criteria applicable to individual formalization.

In view of the hypothesis about the negative distortion effect (see Section 3), which was proved while analyzing the practice of solving problems by means of cognitive maps, *the general adequacy criterion for interpretation of substantial knowledge about a problem situation to the language of the mathematical model and backward* is in the foreground of risk examination.

This criterion is related to:

- interpretation of intermediate substantial model of initial knowledge formulated by an individual while constructing a cognitive map of a particular problem situation to language of mathematical model being formally processed;
- backward interpretation of the mathematical model to a verbal form providing adequate understanding of the map.

At that, the backward interpretation implies understanding on substantial level of those mathematical properties that are attributed to formalized knowledge and thereby to modelled reality. Understanding of these properties creates the base for examination of applicability of the chosen model type to formalization.

Distortions are possible while constructing both a particular cognitive map (first kind risk factors) and templates of verbal interpretation of the map elements by theorists and developers of corresponding informational technologies (second kind risk factors).

The general criterion of interpretation adequacy is related to the group of particular criteria of cognitive clarity and the criterion of (balanced) completeness of influences to a factor considered in more details in Sections 5.2.1 and 5.2.2, correspondingly.

The criteria of extensions proportionality of factor's concept are formulated as a result of detection of causal influence false transitivity risk in cognitive maps. These criteria are considered in Section 5.2.2.

To demonstrate the discovered risks we use the example of the well-known cognitive map as well as fragments of real cognitive maps for solving particular real-world forecast and control problems.

5.2.1 Criterion of mathematical model cognitive clarity

The concept of cognitive clarity of some information, messages, descriptions, etc., characterizes easiness of intuitive understanding. The lack of cognitive clarity appears when a person has much ado, hesitates trying to understand what has been said or written[17]. This can appear in observed deceleration of understanding process.

With the purpose of adaptation of mathematical language of a model and increasing its cognitive clarity for specialists in a problem area, developers of informational technologies create verbal templates of interpretation of relations in a cognitive map to natural language, in other words, interpretation templates. The relation interpretation template is the verbal formulation of content of arbitrary relation in a map that is made specific by substitution of free variables for particular names of factors connected by direct influence. The templates of such kind are introduced, for example, in (Maruyama, 1963; Roberts, 1976; Abramova et al., 2008). As a simple example, let us consider a relation interpretation template expressing positive influence of a factor to another one: increase (decrease) of <name of factor 1>, all other things being equal, causes increase (decrease) of <name of factor 2>.

Substituting particular factor names for free variables in this template we define concretely the relation between these factors while constructing a cognitive map of a situation. While substituting particular factor names, for example, "amount of garbage per area" and "bacteria per area" we obtain the following: increase (decrease) of amount of garbage per area, all other things being equal, causes increase (decrease) of bacteria per area.

In this connection, we can speak of the cognitive clarity from two points of view. On the one hand, stereotyped nature of means of understanding really assists cognitive clarity of one-type constructions. But, on the other hand, with regard to published templates of map relations understanding, nowadays one can see a tendency to simplification of the templates to the prejudice of adequacy of mathematical sense of constructions. Thereby the cognitive clarity of a mathematical model is decreased for the problem area specialists who understand the mathematical sense via verbal templates. An example of application of simplified template creating the risk of inadequate application of the chosen mathematical model to the particular problem situation is considered further by the example of M. Maryuama's cognitive map (Maruyama, 1963).

The cognitive clarity of a situation mathematical model must be provided:

- at the stage of construction of general formal models of cognitive maps or while improving their semantics for user via templates;
- at the stage of construction of particular situation models on the base of cognitive maps.

The cognitive clarity criteria include a group of local particular criteria relating to separate constructions of a map such as a factor, relation, factor with the set of all factors influencing it. Let us consider some of them.

Criteria of normality of factor concept form. In cognitive maps, the factor concepts are twofaced, i.e. they bear double sense (Abramova, 2007). On the one hand this is a factor in a substantial sense. On the other hand, this is a variable possessing values at a definite measuring scale or estimation scale with linearly ordered set of values.

Vagueness and distortions of the substantial sense of model constructions with regard to their mathematical interpretation cause the risk of unreliable estimation of factor influence

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[17] We use the term "cognitive clarity" instead of more habitual "clarity" to emphasize that estimations of these property (within a context of risk problem) have to be made not on the base of a "common sense" of developers of formal models, methods and corresponding informational technologies, but on the base of knoledge of cognitive science and empirical data.

forces, especially for the lack of data for such estimation. One of the risk factors is incomplete understanding of mathematical sense of constructions by a problem area specialist. Such incomplete understanding, in turn, creates the risk of inadequate application of the chosen general formal model to a particular problem situation.

Based on aforesaid, we propose a *criteria of normality of factor concept form* $K^c(p)$. It is assumed that the factor concept p is named in normal form if it can be naturally interpreted (understood) as both a factor in substantial sense and a variable taking on values at a definite measuring or estimating scale. If $K^c(p)$ is met for a factor that is understood in a substantial sense, then the clarity of mathematical model of this factor in the form of a variable of a definite type is provided.

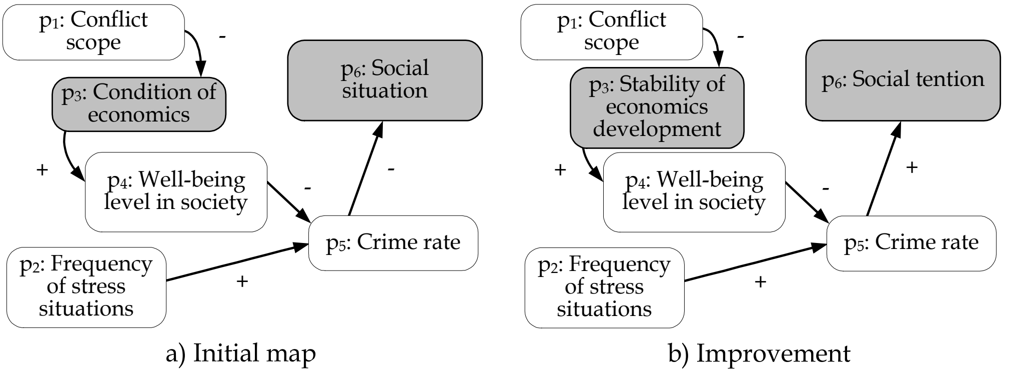

Fig. 6.1. Fragment of the cognitive map of conflict situation and its improvement

Figure 6.1a contains a fragment of the cognitive map of a conflict situation that was constructed based on the results of analysis of experts' representations of development of conflict in former Yugoslavia.

According to the criterion $K^c(p)$, the concepts of factors p_1, p_2, p_4, p_5 are named in normal form. These factors can be naturally considered as the variables taking on values either from numerical scale (if they are measurable) or from estimating scale with verbal values such as "high", "low", etc.

In the view of linguistics, normality appears in natural use of named factor concepts in verbal context such as "more – less", "increase – decrease", "to increase – to decrease", etc. The concepts of factors p_3 "condition of economics" and p_6 "social situation" are the exceptions. Need to use these concepts in such verbal contexts can result in difficulties and one may need certain intellectual effort to find at least content-similar contexts such as "worse – better", etc. This fact shows lack of cognitive clarity of the concept as a variable of the required type.

Correction of a concept in case of its mismatch to the criterion $K^c(p)$ can be made by solely linguistic means without taking into consideration expert knowledge about the a matter of a concept .considered. For example, the concept "condition of economics" can be substituted for "quality of economics condition". However, more valid modelling can be achieved taking into account expert knowledge, at that not only with respect to a matter of concept, but its causal relations with other factors. Then in the considered example one can choose the concept "stability of economics development" instead of "condition of economics" and "social tension" instead of "social situation". Such improvement required change of influence sign between the factors p_5 and p'_6 (see fig. 6.1b).

This example shows that mismatch between the concept and the criterion $K^c(p)$ can be interpreted as insufficient clearness of substantial sense of the factor with respect to the required mathematical sense. Vagueness is the risk factor for the model validity that is discovered as a need in improvement and corrections caused by examination of conformity with the criterion $K^c(p)$. This becomes most evident while converting relations including incorrect concepts to mathematical language.

Criterion of intelligibility of mathematical sense of map construct by verbal template. Intelligibility of mathematical sense of a map construction (in particular, a relation) by verbal template means that to read a certain mathematical property of a construction, for a problem area specialist is sufficient to understand its expression obtained by application of a verbal template for interpretation of corresponding property into a natural language.

More exactly, the sense of the *criterion of comprehensibility of relation by template* $K^b(b_0,Sh)$ applicable to any relation b_0 in a cognitive map consists in the following: the mathematical property assigned to the relation b_0 by the template Sh in accordance with semantics of the general model must be clear for an expert such that adequacy of this property or, at least, its acceptability for expression of the causal relation represented by b_0 from substantial point of view can be estimated.

Criteria of the type $K^b(b_0,Sh)$ with a given templates serve as an auxiliary mean of verification of modelling validity of observable (or assumed) causal relations of factors. Neglecting of examination in accordance with such criteria results in the risk of invalid application of the chosen formal model to a particular situation that can cause invalidity of final results. This is in full conforms the results of research described in (Richardson, 1997).

The distortion of substantial sense of the separate influence, caused by intuitive simplification of the transformation template, creates the risk of inadequate application of the chosen mathematical model to a specific problem situation. This risk may come to effect, for example, in the invalidity of the model application to the specified situation.

The given risk is that of the first kind as far as the distortions are made by people who derive cognitive maps. However, if (1) the misunderstanding of the mathematical sense of the influences is caused by the fact that the designers of decision support technology do not provide a user with, at least, the information on the formal sense of the basic model constructs; or (2) the risky template is included in the definition of semantics of the model which is the basis of the derived cognitive map; the one can reasonably talk of the semantic vagueness as of the risk factor of the second kind that causes distortions.

The detailed description of one of mechanisms of origin of erroneous recommendations given to decision-making personnel that are caused due to ignoring the risk factors at the stage of formalization of initial representations about a problem situation with Maryuama's map is presented in (Abramova & Kovriga, 2008).

5.2.2 The risk of causal influences false transitivity and criteria of factor's concept extensions proportionality

The one can say about violation of transitivity of causal influences if when $A \to B$ ("A causes B") and $B \to C$, $\neg (A \to C)$ actually takes place instead of $A \to C$ what is expected according to the transitivity rule. In other words, C does not essentially depend on A, so A is not an indirect cause of C.

At the same time the causal influences transitivity principle is generally accepted as universal. Accepted as an axiom when modelling situations by means of cognitive maps and other formal methods, it provides an automatic inference of indirect influences.

The risk of violation of causal influences transitivity, on the one hand, has been supposed by authors as a hypothesis coming from theoretical considerations (by analogy to known violation of transitivity of paired preferences "despite obviousness"), and, on the other hand, - violations have been actually found in practice when constructing and applying dynamic maps in order to solve ill-structured situations control problems.

The fragment of the real cognitive map with discovered more complex case of false transitivity through long chains of influences between factors is presented on Fig. 8. The map has been created to analyze the problems related to narcobusiness and drugs use in country "*N*" which has transit narcotraffic on its territory.

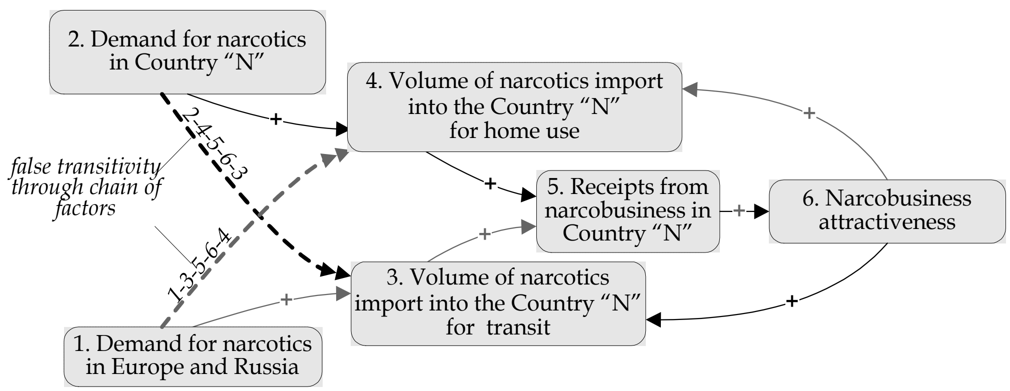

Fig. 8. Fragment of real-life cognitive map of narcosituation with false transitivity

Presented fragment of the map is completed with two indirect influences $2 \xrightarrow{+} 3$ and $1 \xrightarrow{+} 4$ which "are logically deduced" from the chains of direct influences $2 \xrightarrow{+} 4 \xrightarrow{+} 5 \xrightarrow{+} 6 \xrightarrow{+} 3$ and $1 \xrightarrow{+} 3 \xrightarrow{+} 5 \xrightarrow{+} 6 \xrightarrow{+} 4$ accordingly through the transitivity axiom. (Indirect influences are shown by a dotted line).

According to the verbal template of interpretation of influences for Roberts' linear dynamic maps (Roberts, 1976), the mentioned indirect influences $2 \xrightarrow{+} 3$ and $1 \xrightarrow{+} 4$ mean the following: an increase (decrease) in Demand for narcotics in Country "N" causes an increase (decrease) in "Volume of narcotics import into the Country "N" for transit"; an increase (decrease) in "Demand for narcotics in Europe and Russia" causes an increase (decrease) in "Volume of narcotics import into the Country "N" for home use".

However the direct estimation of presence of influences in pairs $2 \longrightarrow 3$ and $1 \longrightarrow 4$ for substantial considerations says that actually in each pair the factors are independent. Thereby in both cases false transitivity takes place.

In this case, in the chain 2-4-5-6-3 not any change in "Receipts from narcobusiness in Country "N" (5), and therefore in "Narcobusiness attractiveness" (6) is caused by change in "Volume of narcotics import into the Country "N" for home use" (4), and in the following influence $6 \rightarrow 3$ a change in "Narcobusiness attractiveness" (6) not necessarily changes "Volume of narcotics import into the Country "N" for transit" (3). In the second chain $1 \xrightarrow{+} 3 \xrightarrow{+} 5 \xrightarrow{+} 6 \xrightarrow{+} 4$ the situation is similar.

Substantially it is possible to explain the false transitivity by the presence of risky (in logic sense) combinations of causal influences in the chain that generates it (transitivity). In this case, in the chain 2-4-5-6-3 not any change in "Receipts from narcobusiness in Country "N" (5), and therefore in "Narcobusiness attractiveness" (6) is caused by change in "Volume of narcotics import into the Country "N" for home use" (4), and in the following influence 6→3 a change in "Narcobusiness attractiveness" (6) not necessarily changes "Volume of narcotics import into the Country "N" for transit" (3). Therefore the given chain of factors does not mean obligatory indirect influence on all chain, and more detailed analysis of influences is required. In the second chain $1 \xrightarrow{+} 3 \xrightarrow{+} 5 \xrightarrow{+} 6 \xrightarrow{+} 4$ the situation is similar.

From the applied point of view, significant aspects of a problem of false transitivity of causal influences when solving concrete practical problems, are the early recognition of situations modelled by means of cognitive map, that can become the reason of false inferences, and their diagnostics for decision-making on correction or even, if the one is impossible, to refusal from the technique chosen.

The analysis of fragments of other cognitive maps with false transitivity shows that their general feature is presence disproportionately general in extension of concepts of factors comparatively to other factors in the chain of direct influences. However the presence of such concepts not always leads to false inferences through transitivity, so we can talk only about risks that require further analysis.

Let us give the formalized definitions *of criteria of factors concept' extension proportionality*, offered in (Abramova & Kovriga, 2008) to help experts to recognize such risky fragments.

In the definition we take into account the fact that has been found out in practice: the same (as a matter of fact) causal influence may be represented in a cognitive map by different concepts so that one may speak about different representations of the influence. Suppose we have factors A, B_1 (represented with the concepts of the same name), which are linked by direct causal influence $B_1 \rightarrow A$, and let there exists (is found by an expert) factor B_2 such that replacement of representation of influence $B_1 \rightarrow A$ with $B_2 \rightarrow A$ does not change the influence substantially, and herewith

$$\mathcal{V}_{B_1} \supset \mathcal{V}_{B_2},$$

where $\mathcal{V}_{B_i}$, $i = 1,2$ - the extension of the corresponding concept, and the relation between extensions is treated as usual set-theoretical inclusion or, that is the same, verbally: "B_1 has bigger extension than B_2", "B_1 is more general than B_2".

Then factor B_2 is *more proportional in its concept extension* then B_1 as the source in the direct influence on A, and factor B_1 is *extensionally excessive* in this influence on A. In other words the concept of factors-sources (causes) is too general comparatively to the factors-receivers (effects), as far as the expert has found less general concept to represent the known influence.

The proposed expert criterion of extensional proportionality $K^S(B,A)$ is applicable to any pair of factors of a cognitive map, connected by direct influence.

The criterion of extensional proportionality for the influence receiver $K^D(A,B)$ is formulated and applied similarly, though in case of many influences on one factor it is less informative for risk detection and error correction.

Using the presented criteria an expert can easily understand in the example considered (fig. 7), that, for example, the concept (5), "Receipts from narcobusiness in Country "N", designating the influence receiver, is excessive in its extension comparatively to the source of influence (4), "Volume of narcotics import into the Country "N" for home use" as far as the influence actually concerns only "Receipts from narcobusiness in Country "N" coming from home use". Similarly excessive in their extensions are the concept of the factor (5) as the influence receiver comparatively to (3) and concept of the factor (6) as an influence source comparatively to (3) and (4).

Let us underline that when allocating disproportionally general concepts on a map using the proposed criteria a question on the ways it can be corrected to except false inference and on the possibility of such correction still remains open.

In rather simple cases with short chains of false transitivity we managed to avoid it by correcting the initial cognitive map. (Abramova & Kovriga, 2008) gives a description of such correction by splitting of the too general concept. The correction considerably changes the results of dynamics of the considered situation and control of its development in order to increase the volume of gas production in the country.) The correction essence is that the way of representation of causal influences known to experts has been changed.

However the considered fragment fig. 7 and other similar examples uncover the following: in internal causal cognitive maps of complex situations experts can have concepts of different degree of generality and corresponding conclusions about the influences. Therefore in the general case the possibility of their representation in the form of "a single-level" formal map is doubtful. The further research of real maps and, probably, complication of applied formal theoretical models of cognitive maps is required.

Finishing the analysis of a problem of risks of causal influences false transitivity in cognitive maps, we will notice that, as shown in (Abramova & Kovriga, 2008), these risks are caused by joint action of two risk factors, including

- disproportion of concepts generality, typical when conceptualizing complex and ill-structured situations;
- the transitivity axiom, that is supported by belief in universality of causal influences transitivity principle.

The disproportion of concepts generality is a first kind risk factor, which in practice comes from both experts and analysts, and intermediaries in formalization; the transitivity axiom is an ineradicably risk factor of the second kind which, by default, is introduced in the end result at the stage of a map formal processing.

6. Concluding remarks

State-of-the-art in the field of both theory and practice related to formal cognitive maps shows two tendencies. On the one hand, experience of their practical applications is accumulated that testifies to their utility for problem solving for ill-structured situations and qualitative knowledge of situations. On the other hand, knowledge of human-induced risks is accumulated as well, this knowledge being not only theoretical one, but also in the form of examples of embodied risks in concrete maps and map-based models.

According to principles of protection against risks proposed in (Abramova, 2007), further research aimed to decrease of riskiness of cognitive-map-based methods should move in two directions:

- development of protective methods for inclusion into human-dependent stages of information technologies supporting existing formal methods beginning from stages of formalization and up to verification of cognitive maps and map-based models;
- development of advanced methods taking account regular human factors (such as false transitivity of causal influences) through all stages of knowledge transformations.

Today the list of human-induced risks and direct errors typical for cognitive-map-based models and methods as well as the list of known criteria for early detection of such risks and errors are far from end; further empirical research into this problem is required (aimed at systematization of risk factors and their practical significance: both as to factors specific to formal cognitive maps and their separate types and general for different subject-formal decision support methods).

As the most significant challenge, following from discovered risk factors of regular action, the problem of false transitivity of causal influences should be treated as worthy of consideration both as the fundamental problem of correct expression of such influences, and as the technological problem of such risk detection with restriction on the analysis time. The following fact discovered in practice seems to be of fundamental importance in the context of this problem: the same (substantially) causal influence can be presented by means of various concepts on a cognitive map (Abramova & Kovriga, 2008). Thereby the problem of false transitivity of causal influences in its fundamental aspect appears closely related to logic and linguistics, being the interdisciplinary problem.

At last, it is necessary to designate the problem of training of users of information technologies based on formal dynamic cognitive maps for modeling ill -structured situations. As researches (Schaffernicht, 2007) have shown, teaching the general concepts which characterize dynamics of processes ("behavior" in contrast to events) brings in difficulties and is connected with cognitive biases. This is also confirmed by our practice and the analysis presented herein. One of the ways to solve this problem, in our opinion, is to develop cognitive training simulators which will help users' model dynamics of complex situations for definite types of cognitive maps in the context of known problem situations.

7. References

Abramova, N.A. (2007). On the problem of risks due to the human factor in expert methods and information technologies. *J. Control Sciences*, No. 2, (Mar/Apr. 2007), (11-21), ISSN: 1819-3161.

Abramova, N.A. (2006). A subject of intellectual activity under cognitive control of ambient intelligence, *Proceedings of 9th IFAC Symposium on Automated Systems Based on Human Skills and Knowledge*, pp. 73-78, ISBN:, Nancy, France, 2006. - http://www.ifac-papersonline.net/Detailed/38844.html

Abramova, N.A. (2002). On forming the interface concepts of computer technologies and on psychological correctness, *Proc. of 2th Intern. Conf. "Cognitive analysis and Situations evolution Control* ,vol. 2, pp.26-35, ISBN: 5-201-149646-4, Moscow. Institute of Control Sciences. 2002.

Abramova, N.A. (1993) General approach to the analisys of external behavior of the plants , presented by functional diagramms, based on equvalent transformations, *Automation and Remote Control*, Vol. 2, No. 3, (June1993), (115-134), ISSN : 0005 - 2310

Abramova, N.A.; Kovriga S.V. & Makarenko D.I. (2009). One Approach to Analysis of Risks due to Human Factors in Decision Support Systems for Ill-Structured Situations, *Proceedings of Conference on Human System Interaction - HSI'2009*, pp. 113-123 , ISBN:1-4244-1543-8, Catania, Italy, May 21-23, 2009.

Abramova, N.A.; Avdeeva, Z.K. & Kovriga, S. V. (2008) Cognitive Approach to Control in Ill-structured Situation and the Problem of Risks. In: *Advances in Robotics, Automation and Control*, J. Aramburo and A.R. Trevino (ed.)., (85-110) , IN-TECH, ISBN : 978-953-7619-16-9, Viena, 2008. – http://intechweb.org/book.php?id=39& content=new&sid=1.

Abramova, N.A. & Kovriga, S.V. (2008). Cognitive Approach to Decition-maiking in Ill-Structured Situation Control and the Problem of Risks, *Proceedings of Conference on Human System Interaction - HIS'2008*, pp. 83-88, ISBN:1-4244-1543-8, Krakow, Poland, May 25-27, 2008.

Abramova, N.A.; Kovriga, S.V. et al. (1999) Seaching of Approach to Problem Solving. SYNTEG, ISBN: 5-89638-018-6, Moscow,1999.

Avdeeva, Z. & Kovriga, S. (2008). Cognitive approach in simulation and control. *Plenary papers, Milestone reports & Selected survey papers. 17th IFAC World Congress*, pp.160-167, ISBN: 978-3-902661-00-5, Seoul, Korea, July 2008. – http://www.ifac-papersonline.net/Detailed/36001.html

Avdeeva, Z.; Kovriga, S. & Makarenko, D. (2007). Cognitive approach to problem solving of social and economic object development. *Proceedings of 4th International Conference on Informatics in Control, Automation and Robotics*, pp. 432–435, Angers, France, may 2007.

Axelrod, R. (1976). The cognitive mapping approach to decision making. In: *Structure of Decision. The Cognitive Maps of Political Elites*, R. Axelrod (ed.), (3-18), ISBN: 069107578-6, Princeton University Press, Princeton.

Chaib-draa, B. (2002). Causal maps: theory, implementation, and practical applications in multiagent environments. J. *IEEE Trans. on Knowledge and Data Engineering*, Vol.14, №6, (november/december 2002), (1201-1217), ISSN: 1041-4347.

Bell , D.E.; Raiffa, H. & Tversky, A. (ed). (1988). Decision Making: descriptive, normative *and prescriptive interactions*, (9–32), Cambridge University Press, Cambridge.

Bouzdine-Chameeva, T. (2006). An application of causal mapping technique ANCOM-2 in management studies, *Proceedings on the 6th Global Conference on Business & Economics*, pp. 11-21, ISBN: 0-9742114-6-x, USA, oktober 2006, Gutman Conference Center, USA.

Dörner, D. (1997). *The Logic of Failure: recognizing and avoiding error in complex situations,* Basic Books, ISBN: 978-0201479485, Massachusetts.

Eden, C.; Ackerman, F. & Brown, I. (2005) The Practice of Making Strategy: Step by Step Guide, Stage, ISBN:076194494 X(pbk), London

Fedulov, A.S.(2005). Fuzzy relational cognitive maps. J. of Computer and Systems Sciences International, , Vol.44, No.1, (2005), (112-124), ISSN: 1064-2307

Gorelova, G.V. & Zaharova E.N.(2006) Structured Analysis of Complex Systems Cognitive Models. *Proc. of VIth Intern. Conf. "Cognitive analysis and Situations evolution Control*, vol. 2, pp.26-35, ISBN: 5-201-149646-4, Moscow. Institute of Control Sciences. 2006.

Heyer, R. J. (1999). *Psychology of Intelligent Analysis*. Central Intelligence Agency. ISBN: 1 929667-00-0

Hodgkinson, G.; Maule, A. & Bown, N. (2004). Causal Cognitive Mapping in the Organizational Strategy Field: A Comparison of Alternative Elicitation Procedures, *Organizational Research Methods*, Vol. 7, No. 1, (Jan. 2004), (3-26), ISSN: 1094-4281, SAGE Publications

Kim, D. (2000). A simulation method of cognitive maps. *Proceedings of 1st International Conference on Systems Thinking in Management.*, pp. 294-299, 2000, Geelong, Australia, Deakins University, Geelong.

Kremer, R. (1994). Concept mapping: informal to formal, *Proceedings of the Second International Conference on Conceptual Structures*, pp. 45-55, ISBN: 3-540-58328-9, College Park, Maryland, USA, Aug. 1994, Springer, Maryland.

Kulba, V.V.; Kononov, D.A. & other. (2004). *Methods for forming development scenario for socio-economic systems,* SYNTEG, ISBN, Moscow.

Kuznetsov, O.P.; Kilinich, A.A. & Markovskii, A.V. (2006). *Influence analysis in control of ill-structured situations based on cognitive maps*. In: *Human factor in control sciences*, N. Abramova, D. Novikov, and K. Hinsberg (ed.), (311-344), URSS, ISBN: 5-484-00391-1, Moscow.

Larichev, O.; Moshkovich H. (1997). *Verbal decision analysis for unstructured problems*, Kluwer Academic Publishers, ISBN: , Boston.

Maximov, V. & Kornoushenko, E. (2001). Analytical basics of construction the graph and computer models for complicated situations. *Proceedings of the 10th IFAC Symposium on Information Control Problems in Manufacturing*, pp.113-225, Vienna, Austria, September 2001.

Maruyama, M. (1963). The Second Cybernetics: Deviation-Amplifying Mutual Causal Processes. *J. Amer. Sci.*, Vol. 5, No. 2, (June 1963) (164-179f), ISSN: 0003-0996, California.

Narayanan, V. K.&Deborah, J. (2005) *Causal mapping for research in information technologies*, Idea groop, ISBN: 1-59140-396-0, Hershey, USA

Peña, A.; Sossa, H. & Gutiérrez, A. (2007) Cognitive maps: an overview and their application for student modeling. *J. Comp. y Sist.,* Vol.10, №3, (Jan./Mar. 2007), (230-250), ISSN: 1405-5546.

Richardson, G. P. (1997) Problems in causal loop diagrams revisited. *System Dynamics Review*, Vol. 13, No. 3, (Fall 1997): 247–252

Roberts, F. (1976). *Discrete mathematical models with applications to social, biological and environmental problems.* Prentice Hall, ISBN: ISBN-13: 978-0132141710, New Jersey.

Schaffernicht, M. (2007). Causality and diagrams for system dynamics. *Proceedings of the 25th International Conference of the System Dynamics Society*, pp. 24-49, ISBN: 978-0-9745329-8-1, Boston, USA, July 29 – August 2, 2007.

Vesa, A. N. (2007). Application of Fuzzy Cognitive Maps to Business Planning Models. In : *Theor. Adv. and Appl. of Fuzzy Logic*, O. Castillo et al. (ed.), Vol. 42 , (119–127), Springer-Verlag, ISBN: 978-3-540-72433-9, Berlin/Heidelberg.

5

From Physical Brain to Social Brain

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1. Introduction

In our highly complex human society, social intelligence is essential for interacting with other agents (Frith et al.; 2004). One of the key elements of social intelligence is the ability to assess *social compatibility (distance)* between oneself and others, e.g. judging whether someone could be a friend or enemy, while also selecting proper behavioural options in our social interaction (Bogardus, 1959; Akerlof, 1997), as it influences our socioeconomic behaviours (Hoffman et al.; 1996; Charness & Gneezy, 2003; Jones & Rachlin, 2006). Across cultures, the nature of interpersonal relationships are often thought of, described and acted out in terms of physical space (e.g. "close friends" or "distant relatives") (Ossowski, 1963; Bottero & Prandy, 2003). In our daily life, social distances are also acted out in our natural behaviours, such as our tendency to regulate "personal space" based on the degree of social connection with others (Hall, 1966; Hayduk, 1983). Moreover, it has been widely observed that there is a tendency for people to cognitively map social distances onto physical space, giving rise to psychological tools such as sandplay therapy and sociograms. However previous neuroscience studies tend to show that social intelligence has strong ties with the emotion-related brain area and the reward-related brain area (Goleman, 2006). Is the connection between spatial concepts and social concepts in linguistics and psychology only a convenient metaphor or based on deep biological roots in the brain?
One intriguing possibility is that the connection between the mental representations of social relationships and those of physical space is based on common neural substrates in the brain (Ramachandran and Hubbard, 2001). In particular, since the parietal cortex is known to be involved in the self-referential operations that convert the spatial information of external objects into self-centred (i.e. egocentric) coordinates for action behaviour (Roland et al.; 1980; Rapcsak et al.; 1995; Neggers et al.; 2006; Naito et al.; 2008), the common origin hypothesis predicts that the parietal cortex should also be engaged in social distance judgments, when a self-referential process is required (Vogeley & Fink, 2003). If the parietal cortex indeed performs analogous operations in social space, such a self-referential mapping of social distance would be an efficient manner of organizing complex social information to guide interactions with others.

2. Social relationships represented in physical space

2.1 A doll-arranging task

We have originally created a new experiment to reveal whether people symbolically organize social relationships on a 'distance' scale when estimating social compatibility with other agents. We call this experiment "a doll-arrangement task" where participants spatially arranged 6-cm-high dolls including a self-doll and other dolls on a 30 × 30-cm stage (Fig. 1). The doll-arranging task was a virtually modified version of the social measurement that was done to measure spatial distance between persons, allowing researchers to carefully observe human natural social behaviours (Hall, 1966; Hayduk, 1983). This task was designed to be easily conducted in an experimental room. By measuring physical distances between a self-doll and other dolls, we may know if people represent social relationships on a 'distance' scale when estimating social compatibility with other agents.

2.2 Free behavior in a doll-arranging task

We conducted a doll-arrangement task on fifteen participants (12 male and 3 female; ages 20–32 years). The participants spatially arranged dolls on a stage (Fig. 1A). Each participant was first asked to place a white doll (representing self) and a black doll (representing an incompatible person) wherever they liked on the stage. Next, he/she randomly picked one doll at a time out of 12 dolls (each had a facial picture of an unfamiliar person), and if he/she felt that he/she would be compatible with the person in real life, he/she had to place it anywhere on the stage. A total of 12 dolls were tested. Even though each participant was allowed to place the compatible dolls anywhere on the stage (Indeed, some participants simply sorted the dolls in a row fashion), the averaged distance between the self and compatible dolls across participants was significantly (physically) shorter than that between the self and incompatible dolls (paired t-test, $t = 4.2$, $df = 14$, $p < 0.001$; Fig. 1B). These suggest that people can choose compatible persons solely based on their facial appearance, and clearly demonstrate that people tend to spontaneously arrange representations of socially compatible individuals near themselves even without explicit instructions to do so. Thus, it is likely that people represent social relationships on a 'distance' scale when estimating social compatibility with other agents.

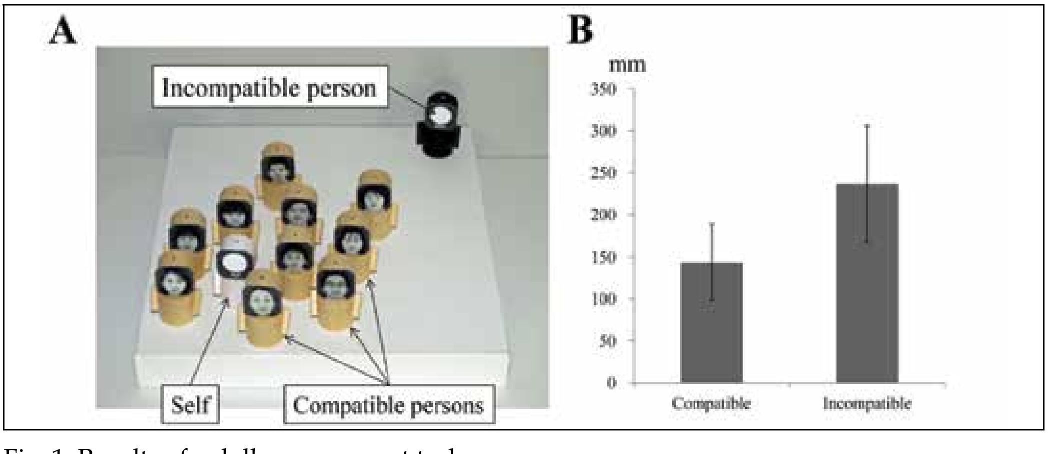

Fig. 1. Results of a doll-arrangement task.

3. A feature in 'distance' evaluation

3.1 Social distance (SD) and Physical distance (PD) task

We conducted a psychophysical experiment to examine whether these two aspects of 'distance' representation have a common feature. Twenty-four healthy volunteers (ages 19–34 years) performed sets of tasks. First, we prepared a physical distance (PD) task and a social distance (SD) task. In the PD task, a display presented two inanimate objects whose relative physical positions could be inferred by texture and lighting cues, and participants indicated which object they judged to be closer to themselves (Fig. 2A). We prepared four different texture panels, and displayed two of those textures in each trial. The two panels were rendered along a virtual line on the monitor (Figure 2A top); this line was tilted at three different angles (15°, 30° and 45°) to the participants' frontoparallel plane. In half the trials, the right panel was closer, and in the other half, the left. In the presentation of the stimuli, the angle of tilt (3), direction of tilt (2) and combination of textures in pairs (12) were counterbalanced. Thus, the task comprised 72 trials. In the SD task, the display presented pictures of two faces, and participants indicated which individual they felt they would be more compatible with and would interact and cooperate with better in real life (Fig. 2B). We used, with permission, facial pictures from a publicly available facial picture database produced by Softopia Japan (Gifu, Japan). The database consists of facial (neutral) pictures of Japanese males and females (ages 15–64 years). We used this database because Japanese faces would be more familiar to the participants, though the individual in the picture was unfamiliar. For the present study, we selected pictures of 36 males and 36 females ranging from 20 to 35 years of age (roughly the same generation as that of the participants). Pictures were paired off in order of age, within the same gender. Each trial stimulus comprised one of these 36 pairs, and each pair was used twice to counterbalance the left-right positions, making a total of 72 trials. The facial pictures were chosen because the facial appearance of a person is known to give us the first impression of the person and if the person is attractive to us we often feel social compatibility to that person, increasing the motivation to build a sustainable relationship (Zebrowitz, 1997).

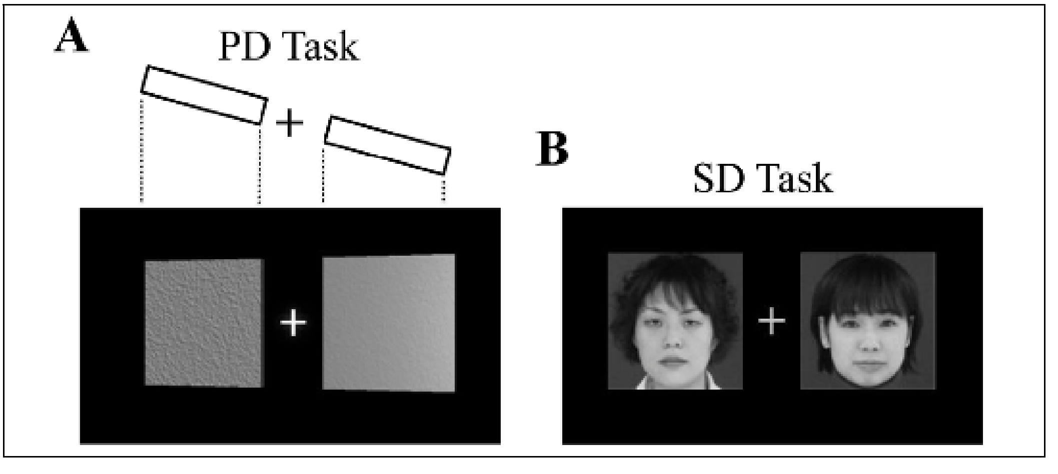

Fig. 2. Examples of stimuli used in the PD and SD tasks

For each task, stimuli were displayed for 3 s per trial, and participants were instructed to press a button as soon as they made a decision. They were also instructed to fixate on a cross displayed at the centre of the screen in order to minimize possible eye movements. Special care was taken so that the locations and sizes of paired stimuli on the monitor were identical across the PD and SD tasks.

3.2 Psychophysical feature in SD and PD tasks

In order to verify a feature in 'social distance' evaluation, the SD task was conducted with an additional rating task after each trial. The participants were also requested to provide a rating (1–5) in the SD trials for how different each pair of faces was in terms of the social compatibility to the participant. As social compatibility seems to be represented on a 'distance' scale (see above), this provided a measure of subjective social distances analogous to the objectively defined distances used in generating the PD stimuli. The reaction times (RTs) in the PD task were sorted into three categories according to the angle of tilt used to generate the stimulus (15°, 30° and 45°), and the RTs in the SD task were sorted into four categories (1, 2, 3 and over 4) based on the ratings provide in the tasks performed outside the fMRI scanner (see below). The mean RT for each category in each task was calculated for each participant.

We found that the reaction time (RT) became significantly longer as the differences in 'distances' decreased, and that this relationship was consistent across both the SD and PD tasks. That is, when pairs of faces were rated as being similar in social distance, the RTs increased ($F(3, 69) = 74.2$, $p < 0.001$, single-factor ANOVA; Fig. 3B). The same trend was seen in the PD task: when the two physical objects were about the same distance from the participant, the RTs increased ($F(2, 46) = 32.0$, $p < 0.001$; Fig. 3A). The graded RTs in the SD task imply that when people evaluate social compatibility with a person and compare these about two persons, abstract magnitudes of their social 'distances' could be compared, as in the case when people compare physical distances from themselves to two objects in the PD task.

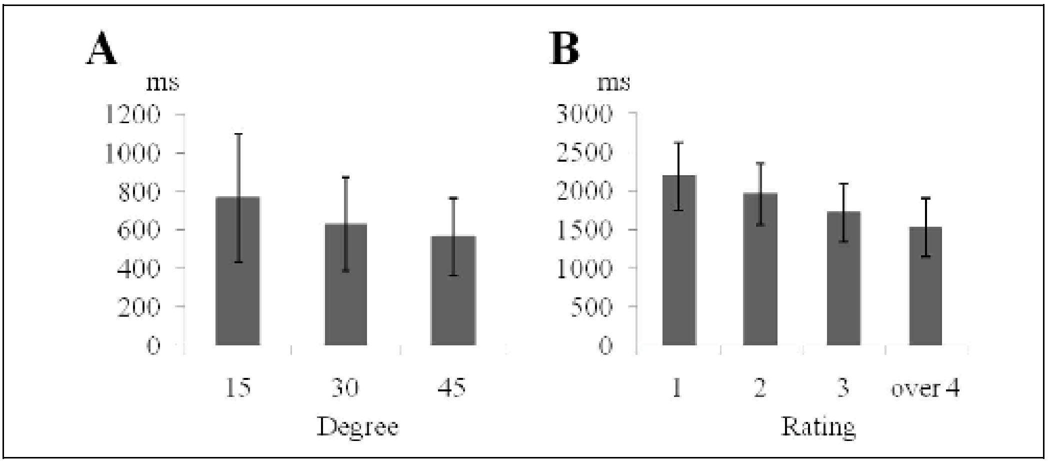

Fig. 3. The results of average RT in the PD and SD tasks

4. Neural correlates of social and physical distance

4.1 Brain activity related to 'distance' analysis

Using a functional magnetic resonance imaging (fMRI), we investigated whether similar brain activity emerges in the evaluation of both physical and social distance, and degree of the brain activation reflects demands of neuronal computation for evaluating abstract 'distance' during the SD task. Twenty-four healthy volunteers who were same individuals in psychophysical experiment participated in the fMRI experiment (details of methods; see Yamakawa et al. 2008).

In order to depict brain areas related to both the PD and SD tasks, we prepared two control conditions (PC and SC, respectively). In these control conditions, participants simply pressed a button in response to the displayed objects or faces that are the same in the PD and SD tasks. Thus, by directly comparing brain activity during the tasks with that during their corresponding control conditions, we may depict activations purely related to the tasks that cannot be accounted by factors of simple visual and motor processing.

4.2 Neural correlates of evaluation of 'egocentric space'

We defined a linear contrast in the general linear model(Friston et al.; 1999) to identify activity that was exclusively related to the PD task by directly comparing it with activity obtained in the control task (PD vs. PC). By this procedure, we could depict brain areas that play essential roles in the PD task and are distinct from those simply related to visual processing and motor response. The same procedure was used to identify activity exclusively related to the SD task (SD vs. SC).

The fMRI analysis revealed that the only brain activity that was significantly associated with the PD task was in the superior aspects of the posterior parietal cortices. This bilateral activation included the intraparietal regions [PD vs. PC, $p < 0.05$ corrected; left and right peak coordinates, (–16, –64, 58) and (22, –68, 52); Fig. 4]. This is consistent with previous notion that posterior parietal cortex is involved in self-referential coding of external objects that is often used for upcoming motor behaviors (Connolly et al.; 2003; Medendorp 2005). The parietal lobule is often activated when people make self-referential spatial judgement of an external object, whereas the lobule becomes silent when people judge allocentric spatial

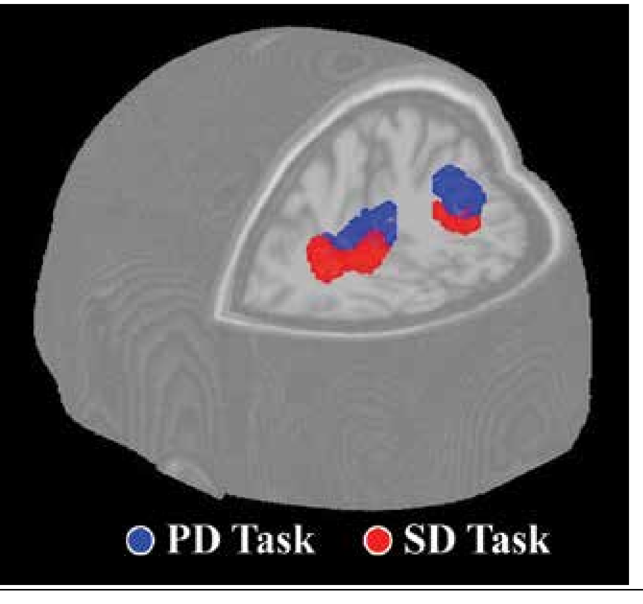

Fig. 4. Brain activations during PD and SD

location of an object (Neggers et al.; 2006). Furthermore, a patient with lesion in the parietal lobule shows impairment in relating her body to external objects (Milner & Goodale, 1995; Rapcsak et al. 1995). All these findings indicate the importance of superior aspect of posterior parietal cortex in humans in a function of self-referential (egocentric) spatial processing of external world such as the estimation of egocentric distances.
Notably, significant bilateral parietal activation was also found during the SD task (SD vs. SC, $p < 0.05$ corrected; peak coordinates, (–38, –56, 46) and (30, –54, 38); Fig. 4A), and these regions overlapped with those of the PD task (47 voxels), in a slightly ventro-lateral portion [peaks of overlapping sections, (–22, –66, 54) and (22, –70, 52)]. As expected, the SD task also activated a network of brain areas consistent with the requirements of visual face processing and general social cognition for the task: the bilateral visual cortices, extending into the fusiform gyri; bilateral medial frontal cortices; inferior frontal cortices; insular cortices; and left basal ganglia and amygdala (Fig. 6A).

4.3 Correlation analysis of 'social distance'

A more stringent method to isolate areas relevant to 'distance'during the SD task is to search for brain areas whose activities scale with the task demands. Subjective ratings of differences in social distance are a putative measure of the task demands (see above). We confirmed that the behaviours inside and outside the scanner were consistent when we analyzed the data obtained by the fMRI experiment. We also performed a correlation analysis across participants to see if there was a consistent trend in which participants who required longer RTs inside the scanner also required longer RTs outside the scanner. As results, the RTs for the SD task also became significantly longer as the differences in 'distances' decreased inside scanner ($F(3, 69) = 11.3$, $p < 0.001$). The average RT which participants required in the SD task were significantly correlated inside and outside the scanner ($df = 22$, $r = 0.69$, $p < 0.001$), indicating the consistency of the SD task demands for participants both inside and outside the scanner.
As their validity was confirmed by the consistency and systematicity of the behavioural data, we then performed parametric modulation analysis across all the brain areas activated by the SD task(SD vs. SC; Fig. 5A) to find voxels whose activation correlated with the demands as measured by the social distance ratings. First, we individually calculated the mean rating for each fMRI blocks. Then, we performed parametric modulation analysis between the ratings and effect size in the block. Effect size was obtained by comparing activity during the block with activity.
The correlation analysis revealed that, within the brain areas active during SD task, only the left intraparietal cortex showed a significant correlation [peak coordinates, (–24, –60, 44); Fig. 5A]. The activity in this region was negatively correlated with the social distance rating, i.e. trials in which the two faces were rated as having similar social distances resulted in greater activation of the left parietal cortex (Fig. 5B). The SD task required the participants to evaluate social compatibility with a person based on his/her facial appearance. As demonstrated in the doll-arranging task, when people evaluate the social compatibility, they tend to think of the compatibility as a 'distance' that can be converted into physical distance from the self-representing doll that brought their egocentric viewpoints (Fig. 1B). Thus, it is assumed that the participants also performed self-referential (egocentric) processing of an abstract magnitude of 'distance' from a person in the SD task, as indicated by the graded RT in this task (Fig. 3B). Then, we found activations during the SD task in the intraparietal

regions that are also active during the self-referential assessment of physical distance (PD) (Fig. 4), and the activity reflected the demands (i.e.; the differences in social distances between self and two persons) of SD task (Fig. 5A, B). These results suggest that the activations should be related to core process of the SD task.

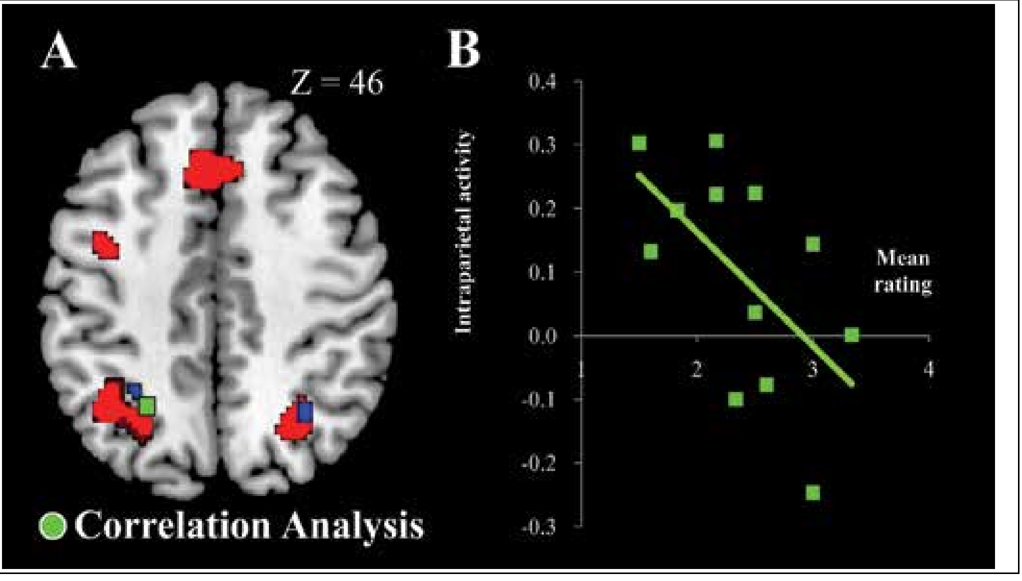

Fig. 5. Brain activations (A), and a representative result from correlation analysis (B)

5. Neural correlates of 'Social distance' and 'Social feature'

5.1 Brain activity related to 'social distance evaluation' and 'social feature judgment'

We investigated if the parietal activation in the SD task is exclusively associated with neuronal computation for evaluating abstract 'distance' from other agents in the egocentric framework. In order to isolate the elements of the SD task related to egocentric social distance, we prepared another task, i.e. a social feature (SF) task. In the SF task, the participants were presented with the same pairs of faces but were asked which would be more 'socially popular' or 'get along with people in general'. This task replicated elements of the SD task, such as the evaluation of facial features or empathetic processing, but lacked the element of self-referential distance. Thus, it is likely that the SD task and the SF task both require common neuronal process related to the analysis of one's facial features and empathetic processing, but only the former activates the parietal cortex imposed a role of self-referential (egocentric) processing of evaluation of social distance.

5.2 Distributed and overlapping representations between SD task and SF task

We compared the activation pattern during the SD task to that during the SF task. Overlapping activation for SD and SF was found in the bilateral visual cortices and fusiform gyri and in the bilateral medial frontal and right inferior frontal cortices [(SD + SF) vs. SC; see Fig. 6]. This suggests a number of areas which might underlie the cognitive functions shared between SD and SF, and some which are unique to SD. In particular, the activation of the parietal cortex appears to be unique to SD. No significant parietal activation was found in the SF task (SF vs. SC), suggesting that the common factors between SD and SF, including eye movements and attentional factors, did not contribute to the parietal activation observed only in the SD task. A direct comparison between SD and SF revealed that SD caused greater activation in the left intraparietal cortex ($p = 0.001$ uncorrected). These differences exist despite the fact that the stimuli for SD and SF were the same and that both RTs, each of which was significantly longer than that of the PD task, indicated similar difficulty levels [SF, 1597 ± 332 ms; SD, 1768 ± 367 ms; PD, 771 ± 197 ms]. Thus, it seems that self-referential (egocentric) evaluation of social compatibility with a person engages the intraparietal regions that are associated with the self-referential assessment of physical distance.

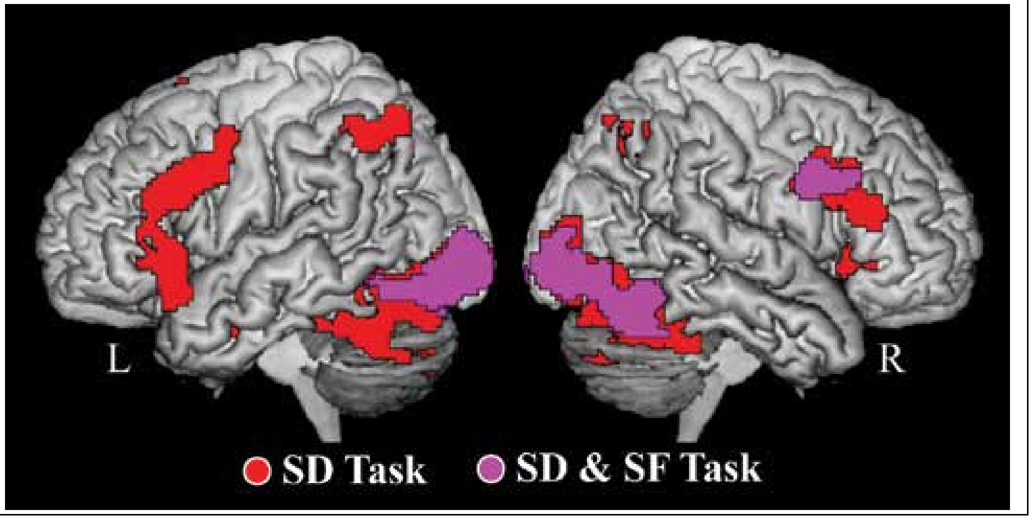

Fig. 6. Brain activations during SD and SF tasks

5.3 Psychophysiological interaction analysis in the SD and SF tasks

Finally, we examined the functional connectivity of the parietal region as a measure of its relevance to the social task. If the activity in the parietal cortex actually mediates the task of assessing social distance based on the face stimuli, then we may expect that it communicates with areas where task-relevant information is processed, such as the fusiform gyrus, which is known to process facial features (e.g. Kanwisher et al.; 1997; Haxby et al.; 2001). While both the SD and SF tasks elicited fusiform gyrus activity, that activity should influence the parietal activity only in the SD task, perhaps via the anatomical connection from the intraparietal cortex to a wide range of cerebral cortices, including the fusiform gyrus, within the same hemisphere (Cavada & Goldman-Rakic, 1989; Rushworth et al.; 2006). We examined such conditional coupling using psychophysiological interaction analysis (Friston et al.; 1997), investigating whether the activity in the parietal cortex receives stronger contextual influences from the fusiform gyrus under the SD task compared to those under the SF task.

Although, the bilateral fusiform gyrus was active in both the SD and the SF tasks, since only the left intraparietal cortex was significantly correlated with the social distance ratings in the previous analysis, we focused on the data obtained from the left hemisphere for this analysis. In each participant, we extracted the time series data from a 5-mm-radius sphere around the peak (–40, –54, –26) of the left fusiform gyrus activity in common between the SD and SF tasks [(SD + SF) vs. SC]. Based on this data, a PPI regressor was computed. We constructed a linear regression model (general linear model) using the PPI regressor as well as the SD and SF regressors used in the first analysis (boxcar × hemodynamic response). Hence, this analysis was specific to the context-dependent influence of each region that occurred over and above the effects of the two tasks.

This analysis revealed enhanced coupling in the SD task between a fusiform region (–40, –54, –26) and an intraparietal region (–40, –62, 42; Fig. 7A, B) within the left hemisphere. Again, this left intraparietal region matched the region active in the SD task ($p < 0.05$, after small volume correction). This supported the context-dependent involvement of intraparietal cortex. Namely, both the SD and SF tasks engaged the fusiform gyrus that plays an essential role in the facial processing, but functional coupling of activities between the fusiform gyrus and the parietal cortex in the left hemisphere was specifically enhanced in the SD task. This suggests that when the brain has to evaluate social compatibility with a person based on his/her facial appearance, the information processed in the facial processing area needs further computation for the evaluation of social distance.

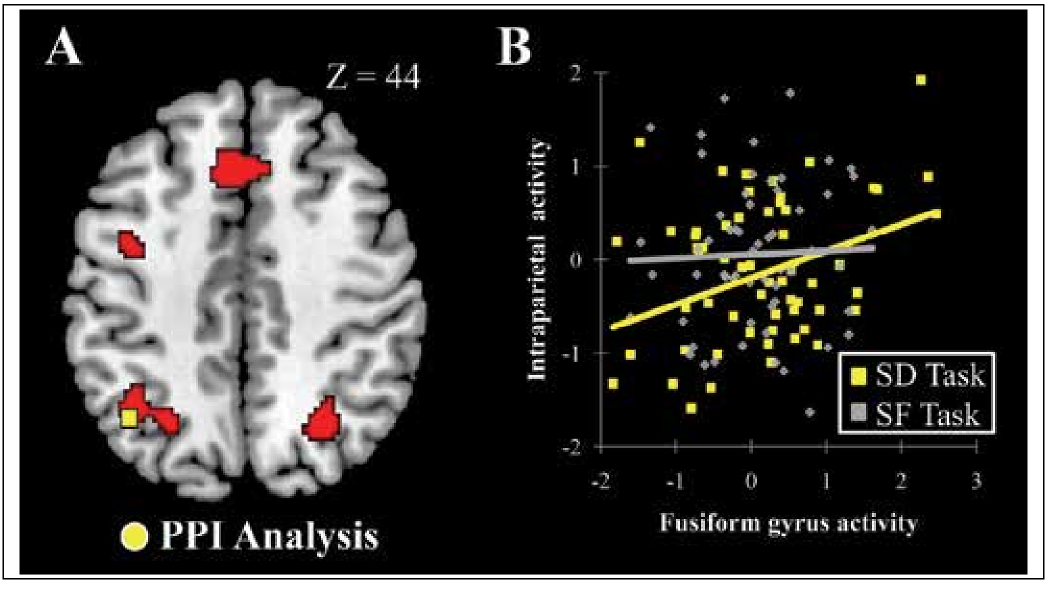

Fig. 7. Brain activations (A), and a representative result from PPI analysis (B)

Neuronal comunication between the ventral portion of the parietal cortex in the human dorsal visual pathway (Milner & Goodale 1992) and the fusiform region in the SD task allows the brain to analyze the distance based on the information of facial features normally analyzed in the human ventral visual pathway.

6. Conclusion

Our results demonstrate that neuronal activity in the human parietal cortex, which is involved in the spatial processing of self-referential physical distance, seems to be associated with the evaluation of social distance between self and others. Thus, our neuroimaging finding raises a possibility that the human parietal cortex may have social-cognitive function in spatial terms that is analogous to its intrinsic properties of spatial function. It means that our ability to judge human relationship in spatial terms may have its evolutionary root in the ontologically older neural substrates for spatial processing. In addition, converting a function of particular brain region related to an ontologically older processing of physical world into the processing for social world could be a basic and general strategy of the brain. The present study may provide an example of this extending function in human social cognition.

In past studies on the neural underpinning of social cognition, much focus has been given to emotional (Baron-Cohen and Belmonte 2005; Frith and Frith, 2006) and reward-related brain regions (Izuma et al.; 2008; Zink et al.; 2008). Our present findings extend the cortical network of social cognition to the parietal cortex by suggesting that the parietal cortex subserves analytic functions in evaluating social relationships (c.f. Chiao et al.; 2008). In order to share a brain function between analyses of physical and social worlds, social quantity should be represented as abstract magnitude of it. Human parietal cortex appears also to be specialized for this purpose because the parietal cortex participates in the processing of magnitudes of temporal discrepancy and of numerical differences (Walsh, 2003; Hubbard et al.; 2005; Piazza et al.; 2007). Growing evidence in non-human primate supports the involvement of the parietal cortex in the social evaluation. Neurons in the intraparietal sulcus exhibit activities that appear to represent values regarding other agents such as female, subordinate and dominant moneys (Klein et al. 2008). Moreover, neuronal activities in the intraparietal sulcus are modulated in a context-dependent manner under a circumstance where 'social' hierarchy exists (Fujii et al. 2007). While neurons in the intraparietal sulcus are classically implicated in the spatial processing of depth (Sakata et al, 1997), those primitive 'social' functions seem to be supported by neurons in the parietal cortex. However, the most striking difference between our human observation and the monkey studies might be that humans can evaluate social distance from other agents based solely on their unfamiliar facial pictures by mentally simulating future outcomes from the cooperation with the agents.

In summary, we found activity in the parietal cortex in connection with a task involving self-referential judgments of social distance. The location of this parietal activity overlapped with areas activated during judgment of spatial distance, suggesting a shared cognitive mechanism, perhaps one of distances in the abstract. This may help explain the linguistic, psychological and behavioural connections between the concepts of the physical and social spaces. Taken together, it seems that parietal cortex may have evolved beyond its original purpose of analyzing physical space, to work as a multi-purpose module for computing abstract distances. Such a co-opting of spatial processing for the purposes of social cognition would seem useful in an evolutionary context, given the scale, complexity and abstractness of relationship networks in human societies. Thus, human beings would have come to evolve and adapt from the brain in physical world to the brain in social world.

7. References

Akerlof, G.A. (1997). Social Distance and Social Decisions. *Econometrica* 65, 1005-1028.

Baron-Cohen, S. & Belmonte, M.K. (2005). Autism: A Window Onto the Development of the Social and the Analytic Brain. *Annual Review of Neuroscience* 28, 109-126.

Bogardus, E.S. (1959). *Social Distance* Yellow Springs, Ohio: Antioch.

Bottero, W. & Prandy, K. (2003). Social interaction distance and stratification. *The British Journal of Sociology* 54, 177-197.

Cavada, C. & Goldman-Rakic, P.S. (1989). Posterior parietal cortex in rhesus monkey: II. Evidence for segregated corticocortical networks linking sensory and limbic areas with the frontal lobe. *J Comp Neurol* 287, 422-445.

Charness, G. & Gneezy, U. (2008). What's in a name? Anonymity and social distance in dictator and ultimatum games. *Journal of Economic Behavior and Organization.*

Chiao JY.; Harada T.; Oby ER.; Li Z.; Parrish T. & Bridge DJ. (2008) Neural representations of social status hierarchy in human inferior parietal cortex. *Neuropsychologia.* Epub ahead of print.

Connolly, J.D.; Andersen, R.A. & Goodale, M.A. (2003). FMRI evidence for a'parietal reach region'in the human brain. *Experimental Brain Research* 153, 140-145.

Friston, K.J.; Buechel, C.; Fink, G.R.; Morris, J.; Rolls, E. & Dolan, R.J. (1997). Psychophysiological and Modulatory Interactions in Neuroimaging. *Neuroimage* 6, 218-229.

Friston, K.J.; Holmes, A.P.; Price, C.J.; Büchel, C. & Worsley, K.J. (1999). Multisubject fMRI Studies and Conjunction Analyses. *Neuroimage* 10, 385-396.

Frith, C.D. & Frith, U. (2006). The Neural Basis of Mentalizing. *Neuron* 50, 531-534.

Frith, C.D.; Wolpert, D.M. & NetLibrary, I. (2004). *The Neuroscience of Social Interaction: Decoding, Imitating, and Influencing the Actions of Others* (Oxford University Press).

Fujii, N.; Hihara, S. & Iriki, A. (2007). Dynamic Social Adaptation of Motion-Related Neurons in Primate Parietal Cortex. *PLoS ONE* 2.

Goleman, D. (2006). *Social Intelligence : The New Science of Human Relationships* (Bantam).

Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in Neurosciences*, 15, 20-25.

Hall, E.T. (1966) *The Hidden Dimension* (Doubleday).

Haxby, J.V.; Gobbini, M.I.; Furey, M.L.; Ishai, A.; Schouten, J.L. & Pietrini, P. (2001). Distributed and Overlapping Representations of Faces and Objects in Ventral Temporal Cortex. *Science* 293, 2425-2430.

Hayduk, L.A. (1983). Personal space: where we now stand? *Psychological bulletin* 94, 293-335.

Hoffman, E.; McCabe, K & Smith, V.L. (1996). Social Distance and Other-Regarding Behavior in Dictator Games. *AMERICAN ECONOMIC REVIEW* 86, 653-660.

Hubbard, E.M.; Piazza, M.; Pinel, P. & Dehaene, S. (2005). Interactions between number and space in parietal cortex. *Nature Reviews Neuroscience* 6, 435-448.

Izuma, K.; Saito, D.N. & Sadato, N. (2008). Processing of Social and Monetary Rewards in the Human Striatum. *Neuron* 58, 284-294.

Jones, B. & Rachlin, H. (2006). Social Discounting. *Psychological Science* 17, 283-286.

Kanwisher, N.; McDermott, J. & Chun, M.M. (1997). The Fusiform Face Area: A Module in Human Extrastriate Cortex Specialized for Face Perception. *Journal of Neuroscience* 17, 4302-4311.

Klein, J.T.; Deaner, R.O. & Platt, M.L. (2008). Social target value signals in parietal cortex. *Curr. Biol* 18, 419-424.

Medendorp, W.P.; Goltz, H.C.; Crawford, J.D. & Vilis, T. (2005). Integration of Target and Effector Information in Human Posterior Parietal Cortex for the Planning of Action. *Journal of Neurophysiology* 93, 954-962.

Milner, A.D. & Goodale, M.A. (1995). Disorders of spatial perception and the visual control of action. In: *The Visual Brain in Action* New York: Oxford.

Naito, E.; Scheperjans, F.; Eickhoff, S.B.; Amunts, K.; Roland, P.E.; Zilles, K. & Ehrsson, H.H. (2008). Human Superior Parietal Lobule Is Involved in Somatic Perception of Bimanual Interaction With an External Object. *Journal of Neurophysiology* 99, 695-695.

Neggers, S.F.W.; Van der Lubbe, R.H.J.; Ramsey, N.F. & Postma, A. (2006). Interactions between ego-and allocentric neuronal representations of space. *Neuroimage* 31, 320-331.

Ossowski, S. (1963). *Class Structure in the Social Consciousness*, trans. by Sheila Patterson (London: Routledge & Kegan Paul).

Piazza, M.; Pinel, P.; Le Bihan, D. & Dehaene, S. (2007). A Magnitude Code Common to Numerosities and Number Symbols in Human Intraparietal Cortex. *Neuron* 53, 293-305.

Ramachandran, V.S. & Hubbard, E.M. (2001). Synaesthesia?A Window Into Perception, Thought and Language. *Journal of Consciousness Studies* 8, 3-34.

Rapcsak, S.Z.; Ochipa, C.; Anderson, K.C. & Poizner, H. (1995). Progressive Ideomotor Apraxia-Evidence for a Selective Impairment of the Action Production System. *Brain and Cognition* 27, 213-236.

Roland, P.E.; Larsen, B.; Lassen, N.A. & Skinhoj, E. (1980). Supplementary motor area and other cortical areas in organization of voluntary movements in man. *Journal of Neurophysiology* 43, 118-136.

Rushworth, M.F.S.; Behrens, T.E.J. & Johansen-Berg, H. (2006). Connection Patterns Distinguish 3 Regions of Human Parietal Cortex. *Cerebral Cortex* 16, 1418-1418.

Sakata, H.; Taira, M.; Kusunoki, M.; Murata, A. & Tanaka, Y. (1997). The TINS Lecture The parietal association cortex in depth perception and visual control of hand action. *Trends in Neurosciences* 20, 350-357.

Vogeley, K. & Fink, G.R. (2003). Neural correlates of the first-person-perspective. *Trends in Cognitive Sciences* 7, 38-42.

Walsh, V. (2003). A theory of magnitude: common cortical metrics of time, space and quantity. *Trends in Cognitive Sciences* 7, 483-488.

Yamakawa, Y. ; Kanai, R. ; Matsumura, M. & Natio, E. (2009). Social Distance Evaluation in Human Parietal Cortex. *PLoS ONE* 4.

Zebrowitz, L.A. (1997). *Reading Faces: Window to the Soul?* (Westview Press).

Zink, C.F.; Tong, Y.; Chen, Q.; Bassett, D.S.; Stein, J.L. & Meyer-Lindenberg, A. (2008). Know Your Place: Neural Processing of Social Hierarchy in Humans. *Neuron* 58, 273-283.

6

The Role of Public Visual Art in Urban Space Recognition

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1. Introduction

People in a modern city are like rats in a maze[1]. They need a tool of space recognition to get acquainted with the environment they have been forced to live in. Historically towns owed their uniqueness to deep roots in local tradition. The central market square constituted the heart of the town. A magic circle of the ramparts and the moat determined a safe and familiar existence space, which the inhabitants could easily recognize and flawlessly identify with. It was the legible street network, connected by the nodes of squares, marking out formally important places, that facilitated the 'wayfinding' (Lynch, 1960) in urban maze. Compact, hierarchical sky-line of the town, dominated by domes of churches and a town-hall tower, constituted a characteristic visual code of urban space[2]. Since the time of Industrial Revolution, cities used to give their inhabitants a sense of security and an opportunity of spatial orientation thanks to their small size and ordered grid layout within a limited area.

Along with spatial expansion of 19th- and 20th-century cities, consequent development of their suburbs and mixture of forms, functions and architectural styles, a **chaos** crept into cities, defined by S. Chermayeff and Ch. Alexander as "modern space salad". Modernism, introducing globally unified architectural patterns and inhuman scale urban structures, rejecting traditional harmony and hierarchy, contributed to the sense of disaffection and alienation in a big city. Simultaneously though, the same modern trends started off the revolution in visual arts. Artists' abandoning lounges for the sake of the streets, freedom of artistic voice and expression of form, inspired a number of research on the processes of artwork perception as well as its social and even political role in the public space (Kwon, 2002).

The paper deals with the theories on urban space recognition and the role of public art in raising the 'imageability' of urban enclosures as well as their cultural quality and social attractiveness. The author presents the **methodology of visual art location in urban public places** on example of Poznan city.

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[1] The E.C. Tolman's experiments on the behavior of rats in mazes, performed in the 1940s, proved that both man and animals create a tentative, mental map to recognize and learn environmental relationships.

[2] The best known historical spatial form records are the waterside panoramas of numerous cities found in the landscape paintings of the 18th century (e.g. the landscape of Venice, Verona, London and Warsaw painted by Bernardo Bellotto, Canaletto).

2. Urban space recognition

The ground-breaking Edward Chace Tolman's discovery of the process of constructing and accumulating spatial knowledge, casted a new light on the perception of urban space and laid a groundwork for mental maps construction as a tool of urban structure recognition. The mental mapping method also allowed to discover what kind of attention people paid to particular places and what role artworks played in recognition and identification of urban space.

2.1 Perception of physical space and urban structure recognition

Visual space perception is a psychological cognitive process consisting in mental copying objects and events of the outer world in relation to the processes which take place in human body. The process of perception was a subject of interest for researchers in a variety of fields: psychology (Gibson, 1950; Tomaszewski, 1986; Bańka, 1999), especially behavioural and environmental psychology represented by H.M. Proshansky, T. O'Hanlon, W.H. Ittelson, L.G. Rivlin. (1977) and others, who analysed the use of behavioural maps; anthropology and sociology (Hall, 1966; Sommer, 1967; Lawson, 2001) as well as geography (Wood, 1992), urban environment research and town planning, developed by K. Lynch (1960), O. Simonds (1961), G. Cullen (1961), D. Appeleyard & J.R. Meyer (1964), Ch. Alexander (1977), A. Rapoport (1977), N.L. Prak (1977), Y.F. Tuan (1977), Ch. Norberg-Schulz (1971) and many others. Some of the fields of research interest were also the visual perception of art (Arnheim, 1954; Miles et al. 1989) and media in urban space (McLuhan, 1964; McCullough, 2004). The *Gestalt* theory[3] has given rise to the **holistic perception** of the space concept which consists in perceiving visual components as organized patterns or wholes, instead of many different parts.

Mental identification is the link between space perception and constructing spatial knowledge. The main achievement has been the discovery of the **cognitive scheme** which controls the processes of perception, recognition and memorisation of physical space. As a result of these processes, a human mind creates an image of the space called a **cognitive map,** making it possible to transform and interpret the data. The selection and interpretation of the perceived information is performed by cultural and personal filters (Rapoport, 1977) and referred to established **cultural patterns** (Alexander et al, 1977).

Along with examining the perception processes, scientists analysed a **spatial code of the city** and **urban structure organisation** which determine orientation and identification of the space. Many of Polish urban and landscape planners, such as J. Bogdanowski, W. Czarnecki or K. Wejchert conducted research on urban space perception as well as townscape and landscape composition, however, their achievements went unnoticed due to the Iron Curtain. Already in 1950s **Władysław Czarnecki** analysed the factors influencing landscape composition, which were also seen from the point of an observer in motion e.g. optical illusion, colour, foreground and background, dominants, rhythm, contrast, frames of vantage points, leading lines, dividing and closing surfaces, nodal points, solids, etc. His observations seem to be similar to later Lynch's conclusions (Böhm, 2004, pp. 41).

Kevin Lynch in his famous book *The Image of the City,* published in 1960, introduced the ***mental map*** term into town planning as a method of **spatial code notation and recognition.**

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[3] The theory initiated by the Berlin School at the beginning of 20th c. (German: *Gestalt* - "form" or "whole") explaining that "The whole is greater than the sum of the parts".

Lynch proves that users perceive and organize spatial information in consistent and predictable ways, creating their own mental maps with five elements: **paths**; **edges**, **districts**, **nodes** and **landmarks.** The five elements determining urban space organisation, have made an important contribution to the development of theories and methods of composing elements of urban structure in the way which is compatible with human psyche needs. The elements also appear in works by numerous European researchers e.g. **M. Trieb**[4] (1970), **J. Castex & P. Pannerai**[5] (1971), **K. Wejchert**[6] (1984) among others.

Paths and **landmarks** seem to be especially useful in the '**wayfinding**'[7] for they serve as important direction lines and reference points in navigation through the city. Series of views, perceived by an observer in motion, create a **chain of mental images**. Cullen's notations of 'serial visions' and McLuhan's 'sequences of the visual space' led to the conclusion that **perception is a dynamic process**. This idea has been developed in *The View from the Road* by D. Appeleyard, K. Lynch & J.R. Meyer (1964), who observed that the speed of receiving visual stimuli by an observer has a crucial influence on urban space perception and recognition[8]. K. Wejchert (1984) introduced a record of visual sequences in the form of a graph of the recipient's emotions, so called "curve of impressions".

In 1970s Michael Trieb proposed a **symbolic code of sequential notation** of urban plan including privileged location in space, closure, limitation of motion, spatial domination, narrowing as well as context continuation. He also emphasised the role of art and "street furniture" in spatial arrangement of public spaces. Trieb's sequential notation was developed in 1998 by E. Cichy-Pazder, who suggested an enriched typology of determiners of perceptive identification (nodes, axis, partitions and dominant signs).

2.3 Between the image of enclosure and the identity of the place

Enclosure, urban and landscape interior, "outdoor room"(Cullen) as well as "positive outdoor space" (Alexander) – all those terms, relating to the space perception, mean a limited landscape unit, built of walls, floor, ceiling (usually sky) and elements of landscape "furniture". Aleksander Böhm emphasises the meaning of the term *enclosure*, which gives space the status of a place. Without the *enclosure,* space loses its sense.[9] The idea of *enclosure*, derived from landscape design (Hubbard & Kimball, 1917; Kepes, 1944) and developed by Gordon Cullen (1961) and Yoshinobu Ashihara (1962), seems to be fundamental for visual art perception in the context of a particular place. **Morphological image** of a city results

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[4] M. Trieb enumerated: roads, borders, central points and direction marks (*Stadtgestaltung, Teorie und Praxis*, 1970)

[5] J. Castex & P. Pannerai singled out: roads/paths, barriers, nodes, zones and landmarks (*Notes sur le structure de l'espace urbain,* 1971).

[6] K. Wejchert selected similar elements of urban composition: streets, regions, border strips, dominants, outstanding elements of landscape, nodal points and distinguishing marks (*Elements of Urban Composition,* 1984)

[7] K. Lynch defined *wayfinding* as "a consistent use and organization of definite sensory cues from the external environment" (*The Image of the City*, 1960).

[8] These discoveries have initiated landscape studies on transportation routes and the research on moving observers' perception. They also influenced the diversity of spatial arrangement of pedestrian zones and transportation corridors (Appleyard et al, 1981).

[9] Goodall, B. (1987), *Dictionary of Human Geography*, Penguin Books, London, p. 152, cited in: Böhm, A. (2004). *„Wnętrze" w kompozycji krajobrazu*

from the relation between the **positive space** (P-space), of determined shape, and the **negative space** (N-space) - formless emptiness. The spatial relations between a form and its surroundings were simultaneously explored by Y. Ashihara (1962) and J. Żórawski (1962), and deepened by Engel & Jagals (1970/1071), J. Tanghe (1976), Ch. Alexander (1977), R. Trancik (1986), J.L. Motloch (1991), S. Bell (1993) and many others. P. Peters (1973) pointed out that a city structure is based on "cells", determining its space identity, and the perception of the space of streets and squares results from human kinaesthetic abilities. According to Yi-Fu Tuan (1977) 'being in a place' is connected with the need of identification, while experiencing the space requires movement from one place to another.

K. Wejchert has developed the theory of urban enclosures, as the basic structural units of the town. In the early 1950s, on the basis of small urban settlements analysis, he singled out 'multi-partial enclosures' (main and added), 'overlapping' and 'centripetal' as well as illustrated examples of using 'leading' and 'closing' lines and surfaces, emphasising observation angle, proportions of enclosures and openings. Many of the phrases included in the early works by K. Wejchert, coincide with much later schemes by Motloch (Böhm, 2004, p. 38).

John L. Motloch (1991) expanded on the theory of place and continued studies on examining **spatial relations of the form** (furniture, sculptures, buildings) and the **background** (landscape and urban walls). He claimed that a city development, from the space perception, point of view should lead to the **intensification of the place sense, its clarity and distinctiveness of form and meaning.**

J.O. Simonds (1961) remarked that the lack of the sense of interior causes discomfort. He paid attention to feelings (excitement, curiosity, limitation, concentration, relaxation etc.) as well as the possibility of controlling and sequencing the views of various landscape enclosures. (Simonds, 1998).

The studies by **K. Lynch'** concentrated on the **identity and structure of city images**. He defined '**imageability'** as "that quality in a physical object which gives it a high probability of evoking a strong image in any given observer. It is shape, colour, or arrangement which facilitate making of vividly identified, powerfully structured, highly useful mental images of the environment. It might also be called *legibility*, or perhaps *visibility* in a heightened sense."(Lynch, 1960, p.9).

The behaviouristic psychology research reveals that the attributes of space which are recognised by observers concerning **continuity, coherence and uniqueness** enable people to **identify a place** (Bosky et al., 1987). After obtaining comprehensive information about the place, it is not anonymous any longer to the observers (Bańka, 1999), which is not, however, identical with identifying with the place. According to Ch. Norbert-Schulz "being in a place" means something more than localisation but results from identification with the place by feeling its character, which can be "natural", "human", or "spiritual". The phenomenological experience of the character of environment, regarded as *genius loci,* combines **simultaneous perception of visual structure** of enclosure with **identification of its cultural and symbolic meaning**. "Every place which has special meaning is actually a centre" (Norbert-Schulz, 1999, pp. 224). Centre is a specific reference point of existence space. Centrality is then an indispensable feature of sacral space which emerges from surrounding chaos and creates a sense of innerness (Mamford, 1961). The meanings of space, place and site (Rendell, 2006) for a contemporary *flâneur*[10], wandering around a maze of the metropolis, have been frequently studied in the context of new media development.

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[10] The figure of *flâneur* (city observer) created by Ch. Baudelaire, was adopted and analysed by Walter Benjamin in *Passagen-Werk* (1921-1940)

2.4 From mental maps to hypermedia maps

Mental maps, which are used in various fields of psychology, education and management, have also been applied in urban and landscape planning as well as architecture and visual arts. Lynch and Appleyars were pioneers in mental mapping studies. Comparing sketches, made by non-professionals, was initially aimed at research on how individuals perceive and navigate through the urban landscape. However, since 1970s this method has been frequently applied to **community collaboration in town planning.** "The idea that local inhabitants need to stir into the planning process the image they have of places – their *personal* images – has become standard practice in city planning. A well-known example involved Randy Hester and the town of Manteo, North Carolina. In 1980 […] using a variety of imaging techniques, Hester uncovered a 'sacred structure' of the residents' downtown and made a map of it as a guide for development."[11]

The growing influence of **cyberspace** on social, economic and cultural relations has been observed for the last ten years[12]. Both exploring a city and social life of their inhabitants take place by means of digital technologies. New communication technologies change the perception of urban space as well as its use (McCullough, 2004), which causes the devaluation of urban public spaces significance as the areas of social integration. In an ironic, but unfortunately possible, vision of ***generic city*** – de-humanised, standard, identity-devoid one - Rem Koolhaas raises the question of the role of traditional public spaces in lives of local communities. Along with the disappearance of social functions, city space becomes devoid of basic diversification factors and, consequently, of its identity (Bonenberg, 2009). Common multimedia culture, dominating over using books or individual perception of objects and phenomena, leads to the situation that in order to interest or even make people come to a particular place, it needs to be advertised on the Internet beforehand (Siewczyński, 2009).

However, the potential of experimental IT supported programs gives also a chance of "reconstruction of identity" of public places as well as creation of new tools for their recognition and navigation. A popular idea based on space identification process is **collaborative mapping**. There are many types of collaborative maps (Google Maps, Wiki Maps etc.) which vary in their target use, subject matter and kinds of users. One of them is a popular ***Open Street Map*** (Wikipedia) working in collaboration with GPS system. Private users can enter new data items into the existing Internet maps concerning historical urban development and significant cultural events, famous ancient monuments, spectacular contemporary buildings and artworks, shopping centres etc, as well as traffic intensity indicators (Bonenberg, 2009). The recent results in the field of digital techniques enable us not only to describe but also visually model the urban space through hypermedia functions.

One of the most difficult challenges is collecting and storing digital data in the place where they come into existence as well as creating an opportunity to use multimedia information on the city in the real space. It is possible thanks to ***Dataspace***[13] system formulated by Tomasz Imieliński, a pioneer in the field of *mobile data*, who described the concept as

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[11] D. Wood: http://www.techkwondo.com/obj/pdpal_msg/PDPal_Denis_Wood.pdf

[12] Since 1988 Internet has been made available to the commercial use, however, just ten years ago, it became a popular communication tool.

[13] The term coined by prof. T. Imielinski, Department of Computer Science Rutgers University, USA

"physical space supplemented with digital information". Both virtual information accessibility in physical urban space and creating digital visualisations, based on real urban structure perception, contribute to better **identification of the city** as well as **identifying with the city**. Interactive virtual games taking place in the urban reality are an attempt to attract teenagers to learning about and co-creating the image of their city.

The urban space recognition and mental mapping based on **hypermedia** may be meant both for action (especially useful for travellers) and for knowledge, as they combine space and mental organisation by relating maps and projects to the images of urban areas, and documents on social history - to their cultural background (Gallet-Blanchard & Martinet, 2002). The information is available through interface elements such as windows, animations, texts referring to urban spaces as well as interchangeable pictures representing historical and contemporary maps or photos taken by users. The social participation in the creation of **hypermedia maps** is achieved by interactivity of form and contents in these media. **Hypermedia programs on urban history** like the CD-ROM *Georgian Cities* (Gallet-Blanchard & Martinet, 2002) or Kyoto Virtual Time-Space[14] can be used both for information and educational purposes as well as city promotion. Such programs are being deployed also in Polish cities: Wrocław, Kraków and Poznań.

Contemporary **hypermedia** are a tool of **meta-perception.** The cyberspace itself, though, constitutes a new virtual maze which requires new tools of recognition.

3. Visual art in public space

3.1 The definition of public visual art in the 20th century

Visual art is an artwork that appeals primarily to the visual sense and typically exists in permanent form, such as traditional plastic art (drawing, painting, sculpture, printmaking) and modern visual art like photography, video, filmmaking, computer art etc.) as well as architecture, design and crafts. The term **public art** (Taborska, 1996; Goldstein, 2005; Finkelpearl, 2000) refers actually to works of art in any media that have been designed and performed with the specific intention of being sited or staged in **physical public domain**, usually external and accessible to all.[15]

Since the ancient times monuments and memorials have been present in public spaces, emphasising the centrality of important sacral and secular places. However, the public sculptures primarily served representative and propagating goals. The notion '**public art'**, as an alternative to elite gallery art, emerged in 1960s, and its aim was to revitalise urban space. Gradually, the most characteristic feature of public art became an opportunity to express current issues and to communicate with its exposition places (Miles, 1997; Kwon 2002; Rendell, 2006) and its recipients (Lacy, 1995). The example of the **Pompidou Centre** in Paris (designed by R. Piano, R. Rogers and P. Rice, and constructed from 1971 to 1977), which is a masterpiece itself, proves that both **permanent** and **temporary** artworks, like happenings, installations and even street theatres, contribute to the **place identity** creation. The **Street Art**, which arose from a need of free artistic expression on the public forum,

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[14] The research programme is conducted at the Ritsumeikan University by interdiscyplinary teem Kyoto Art Entertainment Innovation Research within the framework of the 21st Century COE (Center of Excellence) Research Program.

[15] http://en.wikipedia.org/wiki/Public_art

although not everywhere socially accepted, is also a material of building the **image** of a place(Schwartzman, 1985). 'Street artists' attempt to have their work communicate with common people about socially relevant themes without being imprisoned by aesthetic values.

Determining the role of public art requires considering fashions and trends which have influenced it throughout various periods. In the 1970s and 1980s public art intersected with performance art, conceptual art, installation art, land art, process art, community-based art, and site-specific art. Thus, some art interpretations, sometimes quite remote from the Kantian idea of universally recognised beauty, have appeared, such as Suzane Lacey's '**new genre public art'**[16], which emphasises its social engagement and collaboration. On the post-modern metropolitan urban scene, new elements constantly emerge, claiming the status of public art, like: urban furniture, lighting, multimedia, graffiti and even commercial art.

3.2 Architecture and art as spatial landmarks[17]

In the 20th century, the time of unification of mass building and cultural patterns, art in the public domain took on a very responsible role of creating the **important spatial tags** and building **identity of the place**. Art always stands in opposition to standardization[18]. The inimitable form of public art, situated in the context of unified architecture, constitutes a focal point. But isn't architecture a work of art as well? From the point of view of many artists, architecture forms only frames, background or pedestal for a unique works of art. However, in the city scale, the sculptural forms of architecture take a deserved top position in creating **dominant landmarks** in townscapes, sometimes even regardless of the urban context. Thus, the relevant reply to the above question depends on cultural meaning, aesthetical quality and uniqueness of the object.

The 20th and 21st centuries abound in spectacular examples of architectural icons which have become not only the reference points, but also the aim of cultural tourism (Pearson, 2006), such as artworks by Frank O. Gehry (e.g.: Guggenheim Museum, Bilbao), Daniel Libeskind (the Jewish Museum in Berlin), Peter Eisenman (e.g.: Memorial to the Murdered Jews in Europe, Berlin), Santiago Calatrava (e.g. The City of Art and Science, Valencia), Renzo Piano (e.g.: New Metropolis in Amsterdam, Cultural Centre in Noumea-New Caledonia), Bernard Tschumi (e.g. Park de la Villette, Paris), Enric Miralles (e.g. Iqualada Cementary, Barcelona) and many others. Jane Rendell, in her recent book *Art and Architecture: a Space Between,* analyses significant works created by both artists and architects that seek to blur traditional boundaries between the fields.

Many artists claim that it is the **lack of function** which differs architecture from art. Rendell takes issue with that opinion, saying that "art is functional in providing certain kinds of tools for self-reflection, critical thinking and social change"(Rendell, 2006, pp.3-4). Moreover, there is also architecture without any utilitarian functions – Folly, which is only a

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[16] Lacy, S. (1995). *Mapping the Terrain: New Genre Public Art*. Bay Press, Seattle.

[17] This and the following paragraphs are partially based on author's previous publication: Januchta-Szostak A. (2007). *Methodology of Visual Art Localization in Public Spaces on Example of Poznan City*

[18] Prof. Włodzimierz Dreszer said that "art is anti-thesis of standard" in: Dreszer W. (2007) Przestrzenie wyróżnione krajobrazu kulturowego, (in:) *Sztuka projektowania krajobrazu*, pp. 15-19

decorative accent. Its contemporary example is the Park de la Villette, where Bernard Tschumi in 1982 constructed thirty-five architectural follies.
Since art has abandoned galleries, it may have gained a **range of influence and expression** which is comparable to architectural one. An open outdoor space gives the artists freedom of large works creation incorporating even natural environment (e.g. Richard Long, Robert Smithson, Anthony Gormley, Andy Goldsworthy et al.). Permanent works of art integrated with architecture and landscape design were sometimes included in urban development program like in the case of the new city of **Milton Keyens** in England, designated as a new town at the end of 1960s.
The process of shaping the townscape happens on every **level of perception**: from panorama, dominated by land forms or high-rise objects; through architectural and sculpture compositions organizing space of squares and streets; to human-size sculptures familiar to pedestrians or even urban details. Regardless of its size, the characteristic feature of any artwork is its **unique form which makes it stand out from the surroundings**. Some forms of visual art are dominant, others constitute only accents in urban enclosure, some carry historical or cultural message, others provoke or intrigue by modern form, raising admiration or consternation, nevertheless, they do **individualize** the urban space, becoming important **spatial tags** facilitating orientation and navigation as well as **anchor-points** on mental maps of the inhabitants and tourists.

3.3 Cultural meaning of art and mental anchor-points

Chritian Norberg-Schultz (1999, p.223) remarks that **the purpose of a piece of art** is to retain and convey existential meanings while a human, through perception and understanding the symbol, exposes themselves to an act of identification which consequently gives some meaning to their individual existence. He also emphasizes that the meaning revealed by art in a particular place also determines the character of the place.
The **unique** works of famous architects and artists can now be found in every part of the global village. However, not all of them are able to experience *genius loci* and transform it into art language without losing historical **continuity** as well as cultural and spatial **coherence**. Some of spectacular objects, such as Richard Serra's *Tilted Arc*[19], have never become 'anchor-points' for the local communities. In the Hague, municipal authorities made a great deal of effort to replace the pulled down churches with architectural and sculptural landmarks in order to construct a modern network of anchor-points. The difference between **visual landmark** and **collective anchor-point** lies in mental acceptance and social identification with the artwork. Sometimes inconspicuous sculptures and fountains become **city symbols**, e.g. Neptune in Gdansk, Poznan's famous goats symbol, Mermaid in Copenhagen and Warsaw, or Mannekin Pis in Brussels. This famous statue of a little boy is a perfect representative of the irreverent sense of humour and the unique Brussels' icon.
Unlike **permanent** artworks, **temporary** open air sculpture exhibitions and artistic happenings are transient phenomena, which do not seem to be regarded as permanent points of mental references. However, such short-time but repeatable and intensive events can contribute to building the cultural image and identity of their location places. For

[19] Richard Serra's massive, wall-like steel sculpture was removed from Federal Plaza, New York, in 1989.

example, Pompidou Centre in Paris, or Malta Lake in Poznan are commonly associated with cultural events.

The significance of **commemorative art**, highlighted by many authors (Crinson, 2005), provides the urban space with the historical continuity and integrates local communities. Sculptural architecture of some monuments and memorials, such as the Jewish Museum by D. Libeskind and the Memorial to the Murdered Jews in Europe by P. Eisenman, both located in Berlin – once Nazism's capital, constitute a worldwide symbol of collective memory. Their expressive form and size is as total as Holocaust and shredded like its victims' individual tragedies. The spatial arrangement of the memorials allows gathering and alienation at the same time.

Collective participation in commemoration events builds the feeling of integration based on cultural membership, historical consciousness and social bonds resulting from common moral values. In the post-communist countries like Poland, though, an attitude towards commemorative monuments is ambivalent due to the political changes. The decisive historical transformation of ideology resulted in demonstrations and pulling down monuments, which was a kind of collective manifesto also integrating its participants.

The effect of **social integration** can be achieved via public art by different means: 1) collective participation in commemoration events; 2) spatial arrangement of interactive artworks, which encourages interpersonal relations; 3) social engagement and collaboration on cultural projects.

3.4 From 'site-specific' art to community engagement

The 'site-specific' art is one of many trends set in the second half of the 20th century, however, it has special significance for urban space recognition and spatial arrangement of public places as it deals with urban context. Most of contemporary architects, landscape architects and urban designers attach a lot of importance to architectural context mapping, while artists emphasise the individual expression, autonomy and universality of art.

The art of architecture is always 'site-specific', even though some creators, like Rem Koolhaas[20], preach the provocative commendation of individualism and independence of the artwork from its context. This way or another, context exists and - the basic questions constantly arise: has the intangible **spirit of art** profound implications for place-making or should the artists listen carefully to *genius loci*?

Miwon Kwon (2002) describes the unstable relationship between location and identity as well as controversies around 'site-specific' artworks created by John Ahearn, Richard Serra, and others. It is worth mentioning that in 1970s and 1980s site-specific approaches to public art were promoted and registered within the guidelines of national and state organizations in the United States[21]. The 'design team directive' in the US encouraged artists to share

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[20] Refering to Rem Koolhaas' s slogan: "Fuck the Context"!, in: Koolhaas, R. & Mau, B. (1995) *S,M,L,XL*. Monacelli Press, pp. 495-516, New York

[21] "[…] even though site-specific modes of artistic practice emerged in the late mid 1960s – roughly coinciding with the inception of the Art-in-Architecture Program of the General Services Administration (GSA) in 1963, the Art-in-Public Places Program of the National Endowment for the Arts (NEA) in 1967, and numerous local and state Percent for Art programs throughout the 1960s – it was not until 1974 that concern to promote site-specific approaches to public art" Kwon, M. (2002), pp. 56-63.

responsibilities with architects and urban planners in deciding about spatial arrangement of public spaces. Similar actions have been undertaken in Europe, particularly in the United Kingdom, aiming at creation of 'amenity planning guidance' as well as methodology and framework for cultural mapping and planning (Evans, 2008). During the 1980s local authorities an commercial companies in the UK began to appreciate the value of art in shopping and business development. At the beginning of 21st century landmark sculptures appeared to be also a tourist attraction (Pearson, 2006). Considering growing popularity of cultural tourism, it is quite conceivable that the next step in the evolution of 'site-specific' art will be 'tourist-specific' art.

An ecological trend within 'site-specific' art is also worth mentioning, though it is certainly a subject for a separate publication. Represented by a German artist, Herbert Dreiseitl, it involves creating sculpture and water compositions, introducing rainwater retention, infiltration and recirculation (e.g. Potsdamer Platz in Berlin; Tanner Springs Park in Portland, USA). The variety of water forms and their psychological interactions are also crucial for raising the quality of urban space both in aesthetic and symbolic aspects (Dreiseitl et al., 2001).

In 1993 Suzanne Lacy initiated the program "Culture in Action: New Public Art in Chicago". The new approach, that broke with previous models of '**site-specificity',** was described by Ch. Sperandio as '**community-specific**', and by M.J. Jacob as both '**issue-specific'** and '**audience-specific'** art. It has changed the meaning of public art from the art-in-public-places into the real public-art focused on freedom of expression and active participation of citizens in the artworks creation. Many artists acting at the intersection of art and cultural activism, such as Helen and Newton Harrison, Suzanne Lacy, Stephen Willats, have been developing new forms of creative dialogue with diverse audiences. For the '**new genre public art'**, aesthetical form was only a **medium** of socially and politically relevant content.

3.5 Multimedia and new media in urban culture

The mutual relations between the perception of metropolis and the development of media have been frequently studied[22], under the influence of philosophers such as Georg Simmel or Walter Benjamin (Gallet-Blanchard & Martinet, 2002). There are two main aspects emerging from this line of research: 1) significance and expression of multimedia and new media art in the physical urban space, and 2) perception and popularization of public works of art in the cyberspace.

In the light of '**new genre public art'**, mass as new media are a perfect tool of communication with the general public. However, some kinds of 'audience –specific' art were considered as the art of space unification. Large-size billboards and video installations were often deprived of the name of art as they conveyed the same contents regardless of their localization. Most of west European cities have already solved the problem with billboards located in historical downtowns. In Polish cities, though, there is still an ongoing campaign on exposition area between architecture and sculpture on the one hand and different forms of commercial, advertising art on the other.

Since the video art was born in 1970s it has been exploring alternative strategies of adopting existing urban forms as sites of **artistic intervention**. The artworks by pioneers of video installation, such as Nam June Paik, Gary Hill, Tony Oursler, Sam Taylor-Wood, seemed to be as controversial as Marcel Duchamp's provocative "Fountain", or Cambell's "Soup can".

[22] The subject have been studied by such authos as: McLuhan, 1964; Jenks, 1995; Burgin, 1996; Gallet-Blanchard & Martinet, 2002; McCullough, 2004, Tribe & Jana, 2006 and many others.

However, a remarkable progress in digital technology allowed to create large-size, **interactive video sculptures**, like the Crown Fountain (design by Jaume Plensa, 2004) located in Millenium Park, in Chicago. The fountain is composed of two 15.2 m tall, cubicoid, towers covered with light-emitting-diodes (LEDs) and a black granite reflecting pool placed between them. From time to time the giant LED-screens display enlarged faces of anonymous citizens of Chicago. The Crown Fountain, however controversial in size, is an excellent example of 'community-specific' and socially integrating piece of art. It was praised for its entertainment and artistic features as well as highly accessible spatial arrangement of a common gathering place allowing physical interaction between the public, media and the water.

At the beginning of 21st century IT specialists and artists noticed an immense creative potential of digital technologies and computer- aided design programs (McCullough, 2004) as well as common accessibility of hyper media. **Internet** became a **new public space** for artworks creation, exposition and discussion. The spatial consequence of the approach to creation process and its results is breaking with the monopoly of museums and art galleries as the exclusive places of interacting with art. New Media Art (Tribe & Jana, 2006), as an artistic trend, suggests uniting computer graphics with animation, interactive technologies, computer robotics as well as biotechnology in order to gain new quality in art. The results of work of such artists as Wolf Vostell, John Maeda, Eduardo Kac, show directions of artistic development by means of **new media** (Bonenberg, 2009).

4. Methodology of locating visual art objects in public domain on example of Poznan city

The subject of research conveyed by the author in Poznan was the quality of public areas and possibilities of making them more attractive by introducing monuments and water elements. The activities of municipal authorities consist only in looking for a decent location for the piece of art. The lack of cultural planning guidance made the author search for the art-location methodology enabling not only to improve the visual quality of public places but also to raise the recognisability and 'imagebility' of the city.

One of the first research tasks was creating typology of objects and defining their role in functional and spatial structure of the city. The parallel task was connected with finding the main areas for city image creation. There are three questions frequently arising, which the research was supposed to answer:

1. Which public places are the most important and suitable ones for visual art location?
2. How to arrange those areas to raise the significance, aesthetic and functional values as well as social attractiveness of the public places?
3. What can be the role of visual art forms in different types of urban space?

The process of searching for optimal locations for various types of sculptures as well as spatial arrangement of "outdoor rooms", was divided into three stages, presented by the scheme (Fig.1)

5. The typology of sculpture and water elements as urban details

The typology of public art, from the perspective of artistic composition, is considerably wider than the one presented below. However, for the purpose of the research on the public

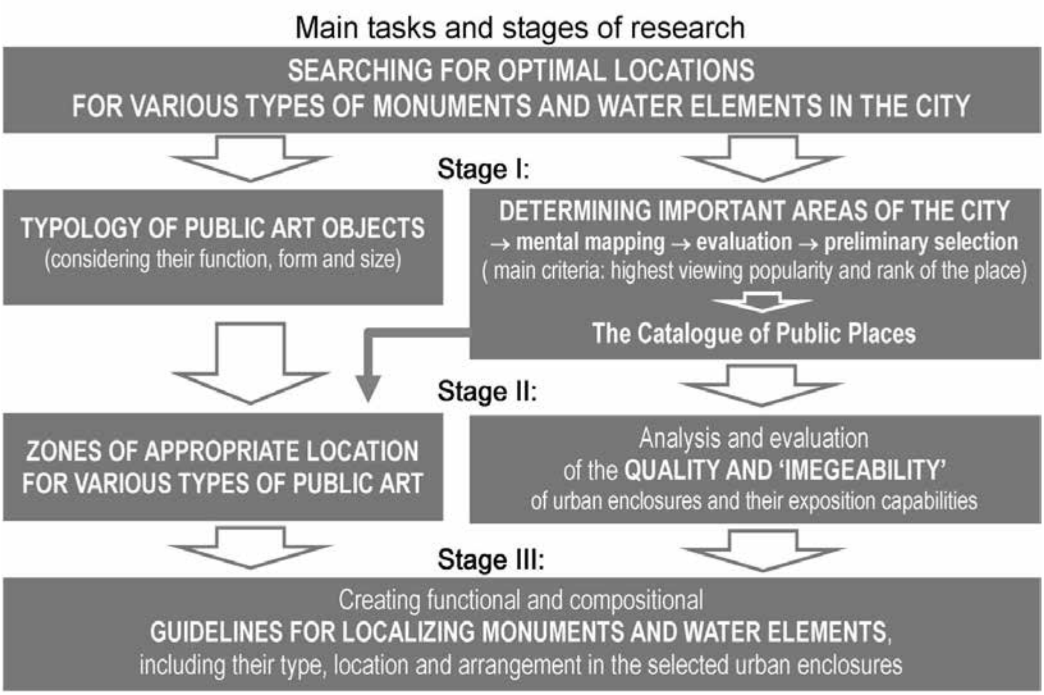


Fig. 1. The analysis of possibilities of visual art location in public domain of Poznan city – main tasks and stages of research

places quality improvement, conveyed by the author in Poznan, several different types of sculptures and water objects were singled out. They differ in manner of placing, compositional values, function, size and their social role. That typology is a kind of pigeonholing, which many of artists would rather avoid, but it seems to be important for creating the planning guidelines for cultural mapping.

6. The stages of the research

6.1 Stage I: the analysis and evaluation of functional and spatial structure of the city with respect to possibilities of locating monuments and water elements

As the public works of art engage in a dialogue with the community and the place, the two main criteria: **'viewing popularity' and 'rank of the place',** appeared to be crucial for determining zones of their location. Initially, the entire area of the city was subjected to the analysis, in order to define the most important public places of the city. Because of high concentration of pedestrian zones and location of the main areas of city image creation, the analysis was subsequently narrowed to the downtown.

The 'space recognition map' was created on the basis of mental mapping method. Students of architecture and citizens of Poznan were asked to select the most frequently visited places as well as the most important ones (in their opinion). As a result, over 120 public places were indicated in the downtown area and subsequently subjected to preliminary selection. The evaluation of public places in accordance with the accepted criteria, was conducted with the use of graphic and statistic methods. The main and sub-criteria, prepared for Poznan city and listed in Table 3, reflect particular aspects of the analysis.

<table>
<tr><td>Table 1.</td><td colspan="6">Determination of type of object</td></tr>
<tr><td rowspan="6">A. Object placing</td><td colspan="6">Direction: directed at one side, two sides, multi-side/in the round</td></tr>
<tr><td colspan="6">Availability: available, unavailable, penetrative</td></tr>
<tr><td colspan="6">Composition: culminating, leading, stopping, closing, framing, scattered</td></tr>
<tr><td colspan="6">Arrangement: enabling gatherings or/and alienation</td></tr>
<tr><td colspan="6">Combination: integrated with building, water element, greenery, urban floor</td></tr>
<tr><td colspan="6">Duration: permanent or temporary exposition</td></tr>
<tr><td rowspan="8">B. Form of sculpture and water element</td><td colspan="6">one-object, multi-object</td></tr>
<tr><td colspan="6">compact, diffused, transparent</td></tr>
<tr><td colspan="6">vertical, horizontal, spherical</td></tr>
<tr><td colspan="6">figurative, symbolic, abstract, realistic, transformed, graphical, textual</td></tr>
<tr><td colspan="6">geometric, organic, combined,</td></tr>
<tr><td colspan="6">static, dynamic, kinetic, interactive</td></tr>
<tr><td colspan="6">site-specific, universal, audience-specific</td></tr>
<tr><td colspan="6">sacral, secular</td></tr>
<tr><td rowspan="6">C. Function of sculpture elements</td><td colspan="6">culture building: commemorative, provocative, self-reflective, socially/politically engaged</td></tr>
<tr><td colspan="6">compositional, decorative,</td></tr>
<tr><td colspan="6">informative, educational</td></tr>
<tr><td colspan="6">advertising</td></tr>
<tr><td colspan="6">entertaining</td></tr>
<tr><td colspan="6">integrating, disintegrating,</td></tr>
<tr><td rowspan="8">D. Function of water elements</td><td colspan="6">composition, decoration, used for foreground or background exposition</td></tr>
<tr><td colspan="6">symbolic</td></tr>
<tr><td colspan="6">serving active or passive entertainment,</td></tr>
<tr><td colspan="6">integrating, disintegrating/ separating (moat)</td></tr>
<tr><td colspan="6">water retention and infiltration</td></tr>
<tr><td colspan="6">ecological</td></tr>
<tr><td colspan="6">climatic</td></tr>
<tr><td colspan="6">utilitarian (e.g. water source,)</td></tr>
<tr><td rowspan="6">E. Size of the object</td><td colspan="2">Estimated size of vertical dimension in comparison to human size</td><td colspan="2">The ratio of height of the object to the height of urban walls</td><td colspan="2">Estimated size of horizontal dimension</td></tr>
<tr><td>XL</td><td>over 6 m</td><td>VXL</td><td>1: 1 and over</td><td>HXL</td><td>over 50% of the floor size</td></tr>
<tr><td>L</td><td>4 ÷ 6 m</td><td>VL</td><td>1: 1,5 ÷ 1: 2</td><td>HL</td><td>31 ÷ 50%</td></tr>
<tr><td>M</td><td>2 ÷ 4 m</td><td>VM</td><td>1: 2 ÷ 1: 4</td><td>HM</td><td>11 ÷ 30%</td></tr>
<tr><td>S</td><td>1 ÷ 2 m</td><td>VS</td><td>1: 5 ÷ 1: 9</td><td>HS</td><td>1 ÷ 10%</td></tr>
<tr><td>XS</td><td>up to 1 m</td><td>VXS</td><td>less than 1: 10</td><td>HXS</td><td>less than 1%</td></tr>
</table>

Table 1. Typology of sculpture and water elements

Table 2. The use of typology of sculpture an water elements on examples of existing objects

Selected examples of artworks	Description of the example and main features of the type	
	A. Object placing	multi-side, available, penetrative, permanent, enabling gatherings, architectural object
	B. Form	site-specific and audience-specific symbolic, geometric, multi-object, dynamic,
	C. Function	commemorative, self-reflective, compositional, informative, educational
	E. Size	XL / VXL/ HL
	Architecture as a sculpture. Fig. 2. The Jewish Museum, author: Daniel Libeskind, location: Linden Str., Berlin (phot. author)	
	A. Object placing	multi-side, available, penetrative, permanent, enabling gatherings and alienation, integrated with urban floor
	B. Form	site-specific and audience-specific, symbolic, geometric, multi-object, diffused, horizontal
	C. Function	commemorative, self-reflective, informative, educational, compositional
	E. Size	M / VS/ HXL
	Fig. 3. "Memorial to the Murdered Jews in Europe", (phot. author) author: arch. Peter Eisenman, location: Ebert Str., Berlin	

A. Object placing	permanent, multi-side, integrated with urban floor, culminating, penetrative, enabling gatherings and alienation,
B. Form	symbolic, geometric, multi-object, compact, dynamic,
C. Function	commemorative, integrating, compositional
E. Size	XL / VXL/ HS

Fig. 4. Poznan Army Monument, authors: artist Anna Rodzińska & architect Józef Iwański, location: Księcia Józefa Str., Poznan (phot. author)

A. Object placing	temporary, multi-side, available, penetrative, leading, scattered
B. Form	multi-object composition, diffused, static, transformed, symbolic, secular
C. Function	integrating, self-reflective, commemorative, compositional
E. Size	S / VS/ HS

Fig. 5. “Unrecognised", author: Magdalena Abakanowicz, location: Cytadel, Poznan (phot. R. Binek)

A. Object placing	directed at one side, unavailable, closing permanent, integrated with water element
B. Form	universal, combined: figurative and geometrical, multi-object, diffused
C. Function	compositional, decorative, additional functions of water: reflecting, separating, retention, climatic
E. Size	S / VS/ HS

Fig. 6. Temporary exhibition of Igor Mitoraj’s sculpture (phot. author), location: Hoover’s Square (the project of spatial arrangement: landscape architect Dorota Rudawa) in Warsaw

A. Object placing	directed at one side, available, permanent, stopping
B. Form	universal, figurative, one-object, compact, static, secular
C. Function	decorative,
E. Size	S / VS/ HXS

Fig. 7. "Eros bendato",
author: Igor Mitoraj,
location: Main Square, Krakow
(phot. author)

A. Object placing	permanent, multi-sided / directed at one side, available, penetrative, stopping
B. Form	multi-object / one-object , compact, static, geometric and textual, symbolic, secular, interactive, audience-specific
C. Function	integrating, self-reflective, decorative, compositional
E. Size	S / VS/ HS

Sculptures inviting observers to co-create the artwork.

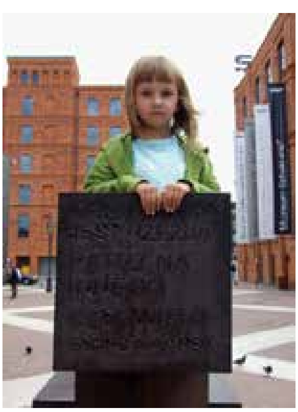


Fig. 8. “Facing Another“
Fig. 9. ”Facing Oneself“,
author: Bucky Schwartz,
location: ‘Manufaktura’ – shopping centre in Łódź
(phot. author)

A. Object placing	permanent, multi-sided urban accent
B. Form	site-specific, static, figurative, symbolic, secular, familiar to pedestrians
C. Function	commemorative, decorative,
E. Size	S / VS/ HXS

Fig. 10. The statue of the "Old Marych" commemorating an old average Poznan citizen,

author: Robert Sobociński, location: Półwiejska Str., Poznan (phot. author)

A. Object placing	multi-side, available, leading, permanent,
B. Form	site-specific, figurative, multi-object, compact
C. Function	commemorative, self-reflective, compositional
E. Size	S / VS/ HXS

Fig. 11. Title of artwork: "Trains to Life. Trains to Death"

author: Frank Meisler, location: Berlin Friedrichstrase railway station, (phot. author)

A. Object placing	permanent, multi-side, integrated with street-furniture
B. Form	site-specific, static, figurative, symbolic, secular, familiar to pedestrians
C. Function	commemorative, decorative,
E. Size	XS / VXS/ HXS

Fig. 12. The statue of "Filutek" commemorating Z. Lengren,

author: Zbigniew Mikielewicz, location: Chełmińska Str./ Szewska Str., Toruń, (phot. author)

Basic criteria	Sub - criteria	Elements of functional-spatial structure of the city	Ratio of importance
Viewing popularity	Connection with main transportation routs	1.1. **vehicles** (transportation arteries, main and collective streets)	O1.1. = 1
		1.2. **public transport**- train, bus and tram stations	O1.2 = 1,2
		1.3. **pedestrians** (main streets, shopping routes)	O1.3 = 1,5
		1.4. **important cycling paths**	O1.4 = 1
		1.5. **water ways**	O1.5 = 0,7
	Connection with main tourist routes	2.1. **The Royal-Imperial Track**	O2.1 = 1
		2.2. **Piastowski Route**	O2.2 = 0.5
	Main areas of services concentration	3.1. **the city center**	O3.1 = 1
		3.2. **centers of districts** and main shopping streets	O3.2 = 1
		3.3**. PIF**, **university campuses**	O3.3 = 1
Rank of the place	The zone of historical development	1. **the core of the city**	R 1.1 = 2
		2. **19th century districts**	R 1.2 = 1
		3. **remaining areas** (20th century)	R 1.3 = 0,5
	Main areas of the city image creation	1. the **axis of the city** (The Royal-Imperial Track and its zone of influence)	R 2.1 = 1,5
		2. **the city "gates"** (Central Station-PIF, river harbor-historical center, Malta-sport center, airport)	R 2.2 = 1,2
		3. **the city's "lounge"** – representative streets	R 2.3 = 1
	Quality of urban space	1. zones of historical structures **under law protection**	R 3.1 = 1
		2. **high concentration of antique buildings**	R 3.2 = 1
		3. **areas of exceptional landscape values**	R 3.3 = 1
	Neighborhood of public cultural and administration institutions	**1 of international, national and regional importance**	R 4.1 = 1,2
		2. of city importance	R 4.2 = 1
		3. of district importance	R 4.3 = 0,7

Table 3. Multi-criterion analysis for Poznan city

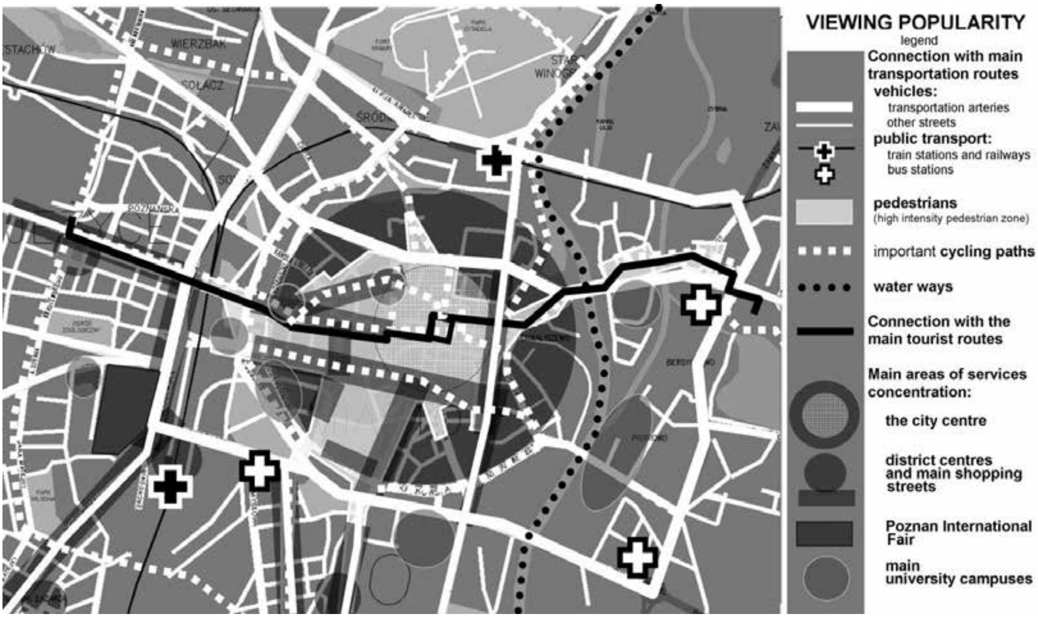


Fig. 13. Poznan - areas of the highest viewing popularity – synthesis

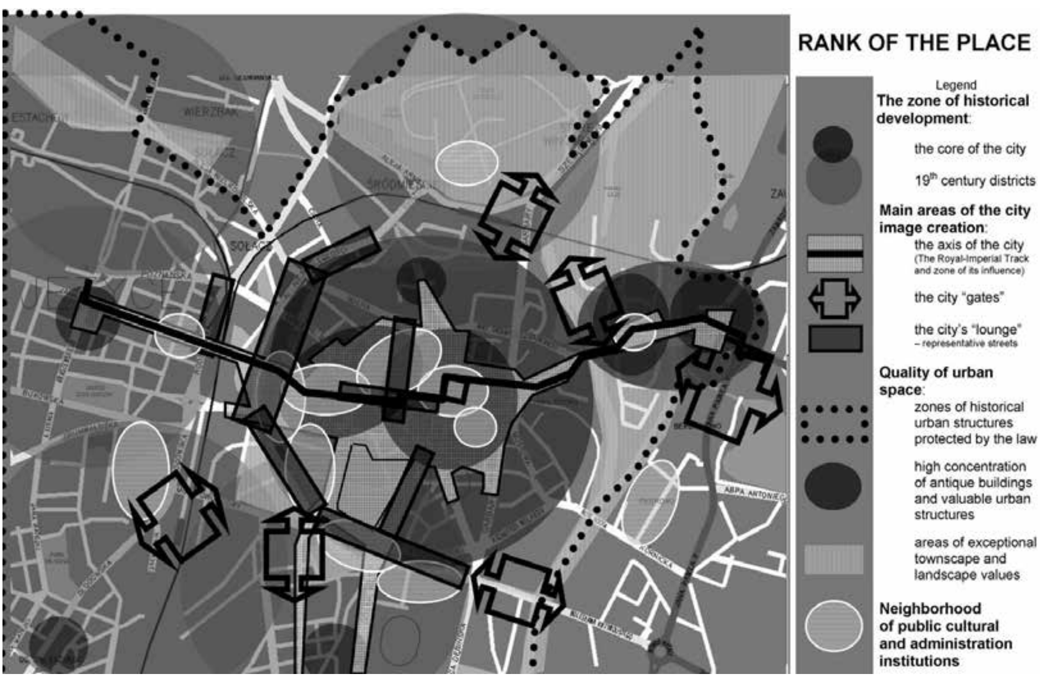


Fig. 14. Poznan - areas of the highest rank of the place – synthesis

After evaluation and preliminary selection, 60 public places (streets, squares, parks, river banks etc.), located in the zones of the highest importance, were described in "**The Catalogue of Public Places in Poznan"**. Information about all individual public places

included the description of their location, neighbourhood, spatial layout and function, short SWOT analysis as well as the preliminary estimation of their capabilities for locating monuments and water elements. All the public places were evaluated in accordance with the criteria multiplied by the ratio of importance to objectify the decision-taking process.
Mental maps have shown formal and informal paths and nodes, which people value most. The comparison of the areas with the results of unbiased analysis of expositional potential of the downtown made it possible not only to determine the best location sites for artworks, but also for '**wounded spaces'** whose expositional potential has not been used due to the lack of decision concerning their final spatial shape. These areas of high importance, frequently situated in the very centre of the city, although constitute the key elements of urban structure as well as nodal points of the main tourist routes, have remained neglected and couldn't be taken into consideration because of low visual qualities. From the social point of view, it was interesting to compare the above schemes (Fig. 13 and Fig. 14) with a map of crisis facts occurrence (e.g. high rate of unemployment, poverty, delinquency, among others), which are commonly observed in the downtown area. The comparison showed that some of the areas which are not eagerly visited and socially degraded are still mentally important and constitute essential reference points in the city's structure.
It is also significant that all the transportation arteries having the best spatial exposure were lined with advertising boards, which depreciate architectural values of the places not only by aggressive colours and unified contents but also by covering valuable views. It would be, therefore, advisable to substitute the advertising objects with sculptures in order to emphasize and individualize the entrances to the city, particularly in transportation nodal points. Considering perceptive capabilities of drivers and the scale of road infrastructure, large size works of art would be recommended.

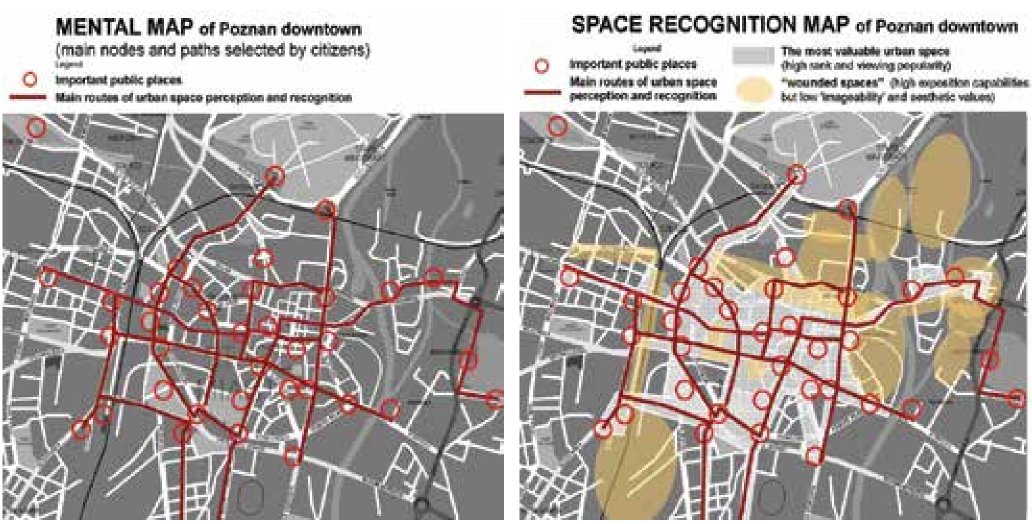


Fig. 15. The comparison of *mental map*, presenting the main nodes and paths selected by Poznan citizens, and *space recognition map*, describing spatial quality of the most important areas of Poznan City.

6.2 Stage II: the analysis and evaluation of the quality and 'imageability' of urban interiors as well as their exposition capabilities

Selected public places having the best expositional values were subjected to spatial and functional analysis in accordance with the detailed criteria described in Table 3. The analysis and evaluation of the quality and '*i*mageability' of urban enclosures covered a variety of aspects and values, namely, **historical, cultural, compositional, aesthetical, functional and social ones as well as the transportation and zoning system**. Special attention was paid to expositional and compositional values, complexity of spatial structures, the quality of architecture as well as historical and cultural meaning of each place and their social integrating capabilities.

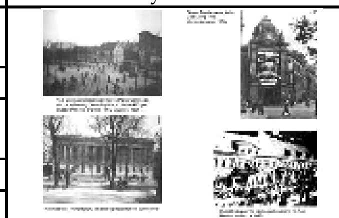
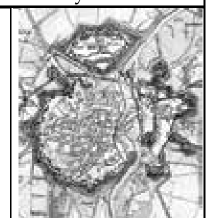
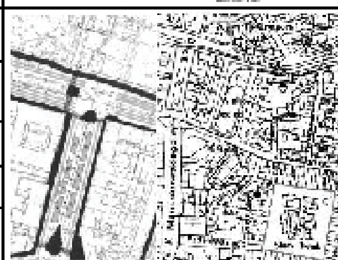
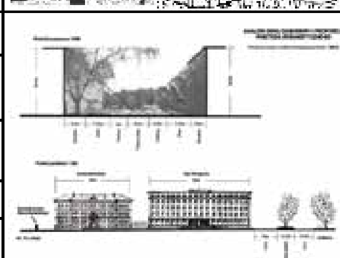
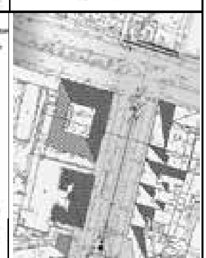
Type of analysis	**Detailed criteria**	**Selected illustrations**: the case study of K. Marcinkowski Alley in Poznań	
Historical and cultural values:	historical background: important events and people		
	previous image of a place		
	location of antique objects and their significance		
	cultural institutions and events		
	social integrating capabilities		
Functional and social values	Functional and transportation zones		
	communicational accessibility and inconvenience		
	social acceptance an problems		
	important public institutions		
	shopping streets and service centres		
Architectural and aesthetic values:	complexity of spatial structures		
	spatial layout enabling to localize elements of urban detail		
	quality of urban walls, floor and „furniture"		
	size and proportions		
	visual quality of the enclosure		
Exposition and compositional values:	visual sequences impression		
	the number of focal points and length of axis		
	potential places for locating visual accents		
	size of exposition field		
	quality of background exposition		
	differences in heights of fields		
	scale and proportions of an object		

Table 4. The criteria of the analysis and evaluation of the quality and 'imegeability' of urban interiors and expositional capabilities for particular public sites

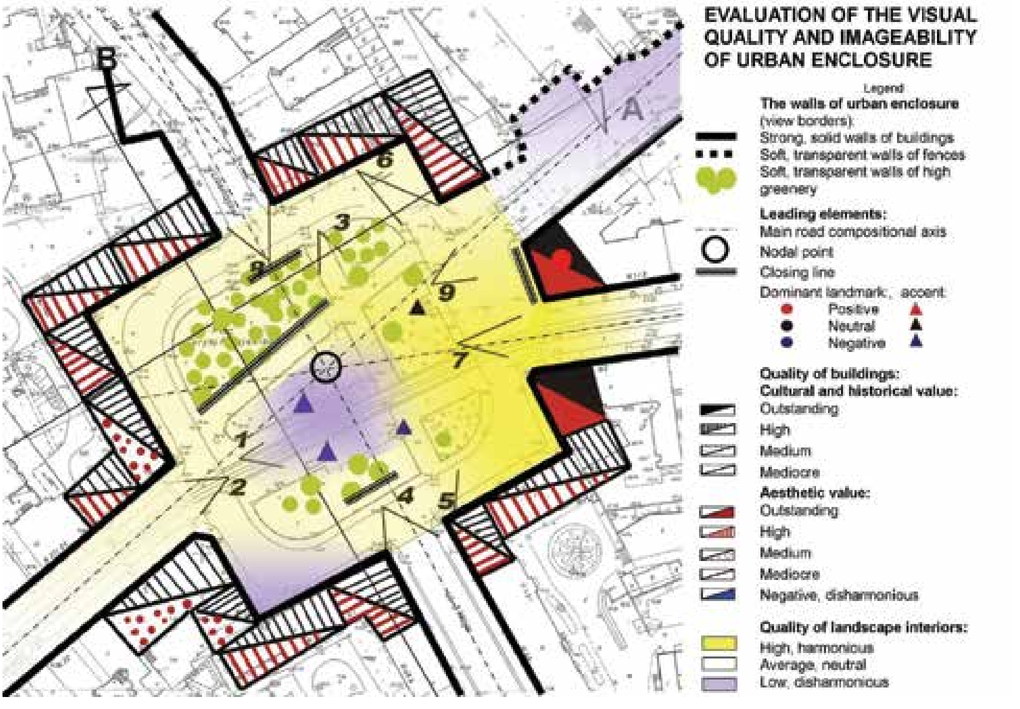


Fig. 16. The evaluation of the visual quality and 'imageability' of C. Ratajski Square in Poznan

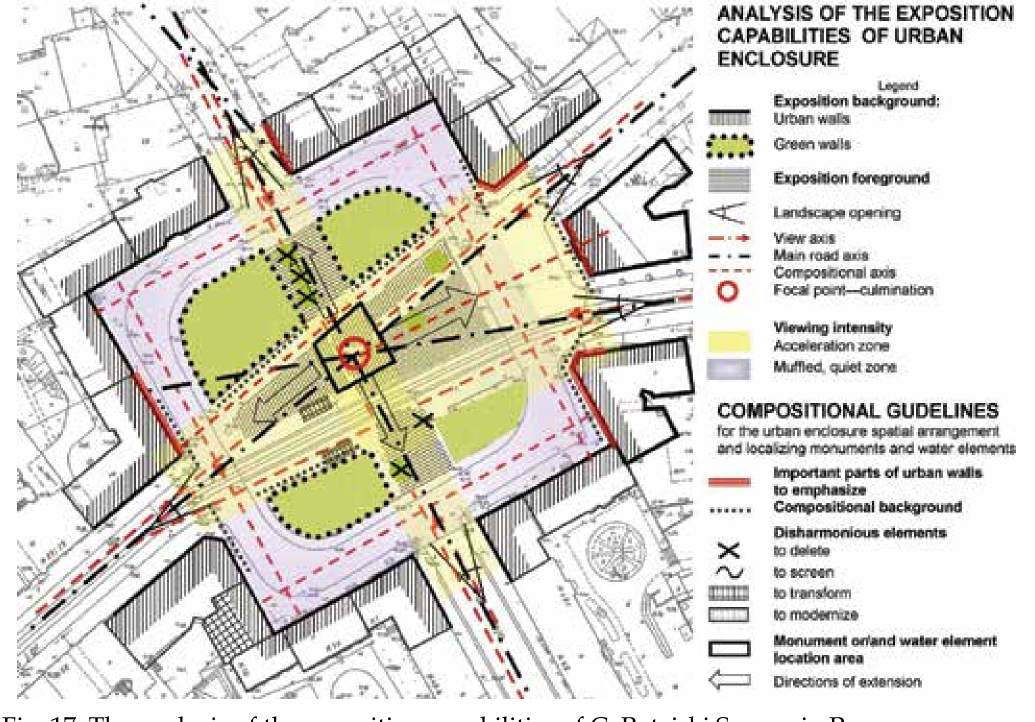


Fig. 17. The analysis of the exposition capabilities of C. Ratajski Square in Poznan

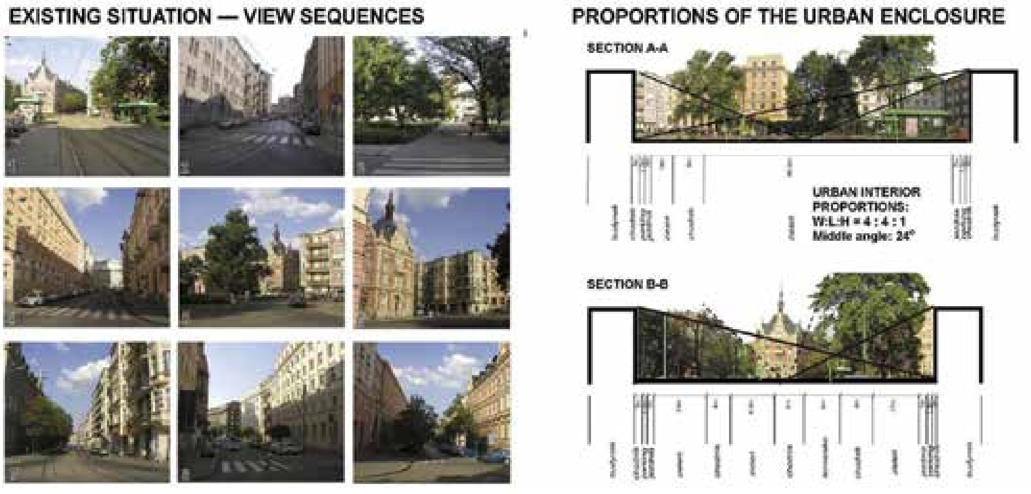


Fig. 18. The analysis of visual sequences impression and spatial proportions of C. Ratajski Square in Poznan

6.3 Stage III: creating functional and compositional guidelines for localizing sculpture and water elements

Majority of the selected urban interiors are situated in the downtown zone of Poznan and constitute the heritage conservation areas. The significance of the places for shaping the city's image made it necessary to determine specific guidelines for their arrangement, considering the lines of urban walls and building height as well as the material and colours of front elevations, the form of the urban floor, greenery and 'furniture', which would be synchronised with the artworks.

The authorities of Poznan were interested in defining the most suitable type of sculpture and water elements' composition for each place, which was necessary in order to establish the conditions for architectural or artistic contest for the spatial form of public art elements and to create guidelines for master plans. However, the research project was extended also by analyzing the role of public visual art in urban space recognition and searching for the most appropriate locations for the place-specific and audience-specific art. The comparison of the viewing popularity research results with some elements determining the rank of particular places and their historical significance was the indicator of the suitable locations for various types of artworks. For example, the communication nodes of the main transportation arteries, as the transit corridors, need landmarks in the form of large scale, 'site-specific' sculptures adjusted to the perception of moving observers. The city gates, like the airport, bus and railway stations constitute a proper location for the 'audience-specific' artworks highlighting the identity of the city. The size of the objects is always dependent on the distance of perception and proportions of particular urban enclosure. Permanent or temporary human-size sculptures, communicating with observers (provocative, entertaining or socially/politically engaged), accompanied by leading or culminating water forms could be located in commercial centres and along the main shopping streets. While the city 'lounges' as well as the squares of high historical significance seem to be suitable for commemorative monuments and memorials, which enable gatherings.

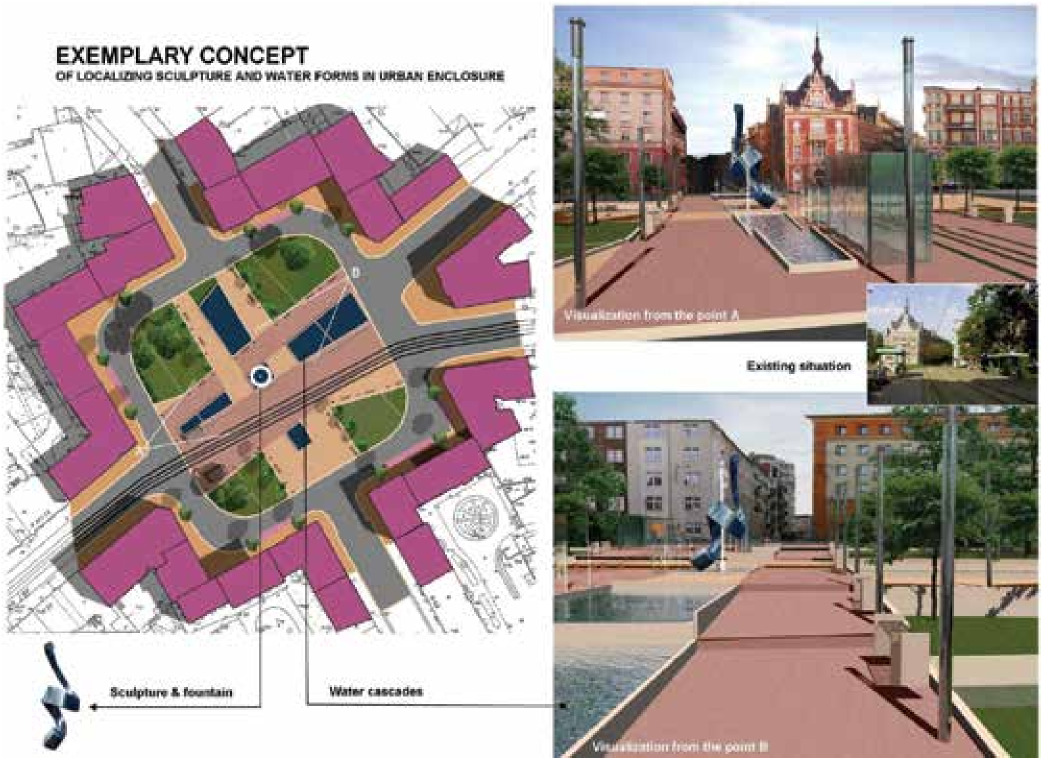


Fig. 19. Exemplary concept of localizing a sculpture accompanied by water forms in urban enclosure – C. Ratajski Square in Poznan

7. Conclusions

Localisation, form and function as well as transfer of contents of artworks play an important role in the process of raising the attractiveness of public spaces and making townscape more individual. It can be a crucial element of visual information system, local community integration factor and the way of building up the identity of public domain.

The presented analysis concentrates mostly on possibilities of artwork location in the most valuable public places. However, another important field of further research seems to be '**wounded-spaces' regeneration**. In the research on downtown structure only 'visually-wounded-spaces' were singled out. A number of 'socially-wounded-spaces' suffer from a phenomenon of identity crisis which shows in the lack of identification of their inhabitants with their place of living. According to the research by British and American specialists, public art can be a significant factor of social integration and activation consequently facilitating the way of perceiving urban space by its inhabitants as their own one, anchored on their mental maps.

The process of transferring public life to virtual reality indicates the need for another stage of research which should be creating a hyper-medial map of Poznan as a modern virtual reflection of multi-layer and multi-aspect processes of perception and recognition of the city space (meta-perception). Its interdisciplinary character would allow the insight both into individual layers of urban structure, districts as well as particular places, buildings and significant artworks. Interactive *dataspace (*with different layers of the urban structure and network of links to information and images of public space in their historical, present and future shape) should make it possible to add and comment on the information by cyberspace users and use the information in real, physical space. Hyper-media map would allow to assess the recognisability of particular areas and their quality, according to residents and tourists, as well as verify their viewing popularity on the basis of page view numbers. It would also allow to evaluate the existing and appraise the designed artworks' locations in public places thanks to virtual visualisations.

8. References

Alexander, Ch.; Ishikawa S. & Silverstein M. (1977). *A Pattern Language,* Oxford University Press, ISBN 74-22874, New York

Appleyard, D; Lynch, K. & Meyer, J.R. (1964).*The View from the Road*, MIT Press, Cambridge MA

Arnheim, R. (1954). *Art and Visual Perception,* California

Bańka, A. (1999). *Architektura psychologicznej przestrzeni życia*, Gemini-Print, ISBN 83-901059-3-4, Poznań

Bennett, S. & Butler, J. (eds.) (2000). Advances in Art and Urban Futures Volume 1: *Locality, Regeneration and Divers[c]ites*, Intellect Books, ISBN 9781841500461, Bristol

Bonenberg, A. (2009). Cyberspace and spatial identity, *Scientific Journal of Poznan University of Technology "Urban Identity in the Times of Globalization*", Vol. 18, No. 10/2009, Poznan, pp. 59- 66, ISSN 1507-6407

Bosky, P.; Jarymowicz, M.; & Malewska-Peyre H. (1992). *Tożsamość a odmienność kulturowa*, Warszawa

Böhm, A. (2004). *„Wnętrze" w kompozycji krajobrazu*, Wydawnictwo Politechniki Krakowskiej, ISBN 83-7242-303-2, Kraków

Cichy-Pazder, E. (1998). *Humanistyczne podstawy kompozycji miast,* OKUPK, ISBN 83-911232-1-9, Kraków

Crinson, M. (ed.), (2005). *Urban memory: history and amnesia in the modern city*, Routledge, Routledge, ISBN: 978-0-415-33406-8

Cullen, G. (1971). *The Concise Townscape*, Architectural Press, ISBN 0-7506-2018-8, Oxford, first edition: Cullen, G. (1961) *Townscape*, Reinhold, New York

Dreiseitl, H.; Grau, D. & Ludwig K.H.C. (2001). *Waterscapes*, Birkhäuser, ISBN 3-7643-6410-6, Basel

Evans, G. (2008). Cultural mapping and sustainable communities: planning for the arts revisited, *Cultural Trends*, Volume 17, Issue 2, June 2008, pp. 65 - 96 DOI: 10.1080/09548960802090634

Gallet-Blanchard, L. & Martinet, M.M. (17. October 2002). *Hypermedia and Urban Culture: a presentation on the CD-ROM Georgian Cities,* Centre *Cultures Anglophones et Technologies de l'Information* CATI, Université Paris-Sorbonne – Paris, Pdf.: http://computerphilologie.lmu.de/jg02/gallet-martinet.html

Gibson, J.J. (1950). *The perception of the visual world*, Boston

Hall, E.T. (1959) *The Silent Language,* Polish edition: (1987). *Bezgłośny język*, Wyd. PIW, ISBN 83-06-01325-5, Warszawa

Hall, E.T. (1966). *The Hidden Dimension*, Anchor Books, ISBN 0-385-08476-5

Januchta-Szostak A. (2007). Methodology of Visual Art Localization in Public Spaces on Example of Poznan City, *Town Planning and Architecture,* Vol. XXXI, No 1/2007, pp. 29-38, Leidykla Technika, Vilnius, ISSN 1392-1630

Kwon, M. (2002). *One Place After Another: Site-Specific Art and Locational Identity*, MIT Press, ISBN: 0-262-11265-5, Cambridge MA.

Lacy, S. (1995). *Mapping the Terrain: New Genre Public Art,* Bay Press, Seattle.

Lynch, K. (1960). *The Image of the City,* MIT Press. ISBN-13: 9780262620017, ISBN 0262620014, Cambridge

McCullough, M. (2004). *Digital Ground: Architecture, Pervasive Computing, and Environmental Knowing*. MIT Press, ISBN: 0262134357

McLuhan, M. (1964).*Understanding media: the extensions of man*, McGraw-Hill, New York; Gingko Press (2003), ISBN 1584230738, 9781584230731

Miles, M. (1997). *Art, Space and the City: Public Art and Urban Futures*, Routledge, ISBN 0-203-97311-9, London - New York

Motloch, J.L. (1991). *Introduction to Landscape Design*, Van Nostrand Reinhold, New York

Norberg-Schultz, Ch. (1975*). Meaning in Western Archtecture*, Polish edition (1999): Wydawnictwo Murator, ISBN 83-912841-0-7, Warszawa

Patterson, Barry (2005). *The Art of Conversation with the Genius Loci*. Cappall Bann Books. ISBN 186163-1693

Pearson, L.F. (2006). *Public Art Since 1950,* Osprey Publishing, ISBN 074780642X

Proshansky, H.M. (1987). *The Field of Environmental Psychology: Securing its Future. Handbook of Environmental Psychology*, D. Stokols and I. Altman, John Wiley & Sons, New York

Rendell, J. (2006). *Art and Architecture: a Space Between*. I. B.Tauris & Co Ltd., ISBN-13: 9781845112226, London

Schwartzman, A. (1985), *Street Art*, The Dial Press, Doubleday & Co., ISBN 0-385-19950-3, New York

Siewczyński, B. (2009). The virtual reconstruction of Poznań city as an instrument of architectural marketing, *Scientific Journal of Poznan University of Technology "Urban Identity in the Times of Globalization"*, Vol. 18, No. 10/2009, Poznan, pp. 67-74, ISSN 1507-6407

Taborska, H. (1996). *Współczesna Sztuka Publiczna*, Wydawnictwo Wiedza i Życie, ISBN 83-86805-31-5, Warszawa

Tolman, E.C. (1948). Cognitive Maps in Rats and Man. *Psychological Review*, 55, 4, (July 1948), pp. 189-2008, ISSN 0033-295X

Tołwiński, T. (1948). *Town Planning,* Vol. I, *Development of the Town in the Past*, Polish third edition: Trzaska, Evert & Michalski, Warsaw

Trieb, M. (1977). *Stadtgestaltung Theorie und Praxis,* Braunschweig: Vieweg

Tribe, M. & Jana, R. (2006). *New Media Art*, Taschen, ISBN 3822830410

Tuan, Y.F.; Mercure, T (2004). *Place, Art, and Self*, University of Virginia Press, Santa Fe, NM, in association with Columbia College, Chicago, IL. ISBN 1930066244,

Wejchert K. (1984). *Elementy Kompozycji Urbanistycznej*, Arkady, ISBN 83-213-3151-3, Warsaw

Wood, D.; Fels, J. (1992). *The Power of Maps*, Guillford Press, ISBN 0898624932. OCLC 26399801, New York

7

The Representation of Objects in the Brain, and Its Link with Semantic Memory and Language: a Conceptual Theory with the Support of a Neurocomputational Model

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1. Introduction

A fundamental problem in cognitive neuroscience is how the brain realizes semantic memory. It is generally accepted that semantic memory consists of stored information about the main features of an object, some processing mechanisms which allow a person to retrieve these features from partial cues, and to link them with lexical aspects and words. The final result is a kind of knowledge which is context independent, can be shared with other people and can produce language and thought (Tulving 1972).

Many conceptual theories of semantic memory have been proposed in past decades, based on two fundamental pieces of information: the behavior of patients with neurological lesions in specific brain areas, who exhibit deficits in word recognition, and results of more recent neuroimaging studies, putting in evidence which different brain areas participate to semantic tasks. The interested reader can find several excellent review papers on the subject (Martin & Chao 2001; Hart et al. 2007). Just the main fundamental issues, essential for the comprehension of the present chapter, are summarized below.

First, most theories agree in assuming that semantic memory is not a localized process, but one which involves a highly distributed representation of features and which engages several different cortical areas, located in the sensory and motor regions of the cortex. This concept may help explaining the existence of patients with category-specific semantic deficits (for instance, patients with impairment in word recognition for living things but no impairment for recognition of non-living objects, or patients with impairment for nouns vs. verbs (Warrington & Shallice 1984; Caramazza & Shelton 1998)). Damasio (Damasio 1989), suggested that semantic representation is fragmented in many motor and sensory features, which must then be integrated in a “convergence zone”. Accordingly, Warrington et al. (Warrington & McCarthy 1987), assumed the presence of multiple channels which separately process sensory and motor aspects of objects; these two main systems would be especially important to identify living and non-living objects, respectively. Several subsequent extensions, improvements or variations of this theory were formulated by various groups (Caramazza et al. 1990; Lauro-Grotto et al. 1997; Humphreys & Forde 2001; Snowden et al. 2004; Gainotti 2006). Nevertheless, all these theories substantially agree in assuming that the semantic system is realized by means of an integrated multimodal network, in which different areas store different modality-specific features. Some theories can also account for the emergence of categories from features: for instance, Tyler et al. (Tyler et al. 2000), in a conceptual model named "Conceptual Structure Account", suggested that objects are represented as patterns of activation across features, and that categories emerge from those objects that share common features and are highly correlated. Hart, Kraut et al. (Kraut et al. 2002; Hart et al. 2002) imagined that object representation is encoded not only in sensorimotor but also in higher-order cognitive areas (lexical, emotional, etc…) and all these representations are integrated via synchronized neural firing modulated by the thalamus. Barsalou et al. (Barsalou et al. 2003) assumed that groups of neurons are coactivated to represent collection of features, and that these groups of features encode progressively more generic information from sensory perception to higher cognitive associations. Moreover, they assumed a topography principle, according to which the spatial proximity of neurons reflects the similarity of the encoded features.

The previous conceptual theories, and others not listed here for briefness, although of the greatest value for cognitive neuroscientists, are just qualitative. In particular, the mechanisms responsible for integrating a distributed information into a coherent semantic representation, their physiological reliability in terms of neural structures, the learning rules for synaptic plasticity, are all aspects which deserve a more quantitative analysis. Modern neural network models, and computer simulation techniques now allow conceptual theories to be translated into a quantitative integrated system of neural units, and the consequent emergent behavior to be analyzed in detail, incorporating training aspects which mimic real synaptic plasticity rules.

A few previous models, based on neural networks with "hidden units" have attempted to reproduce how sensory information (for instance the visual one) can recall the linguistic information, and vice versa (Rogers et al. 2004) or to simulate category-specific semantic impairment (Small et al. 1995; McRae et al. 1997; Devlin et al. 1998; Lambon Ralph et al. 2007). All these models exploit a supervised algorithm (such as the back propagation) for training the network to solve the requested task: pathological deficits are then simulated assuming some damage in network synapses. A more sophisticate model, able to simultaneously retrieve multiple objects stored in memory, was presented by Morelli et al. recently (Morelli et al. 2006). In the model, features are coded by neurons which work in chaotic regimen, and the retrieval process is achieved via synchronization of neurons coding for the same object.

In recent years, we developed an original model (Ursino et al. 2006; Ursino et al. 2009; Cuppini et al. 2009) which aspires to explore several important issues of semantic memory, laying emphasis on the possible topological organization of the neural units involved, on their reciprocal connections and on synapse learning mechanisms. Some problems that the model aspires to investigate are: how can a coherent and complete object representation be retrieved starting from partial or corrupted information? How can this representation be linked to lexical aspects (words or lemmas) of language? How can different concepts be simultaneously recalled in memory, together with the corresponding words? How can categories be represented? How can category-specific deficits be at least approximately explained? What are the mechanisms exploited in bilingualism?

The model assumes that objects are represented via different multimodal features, encoded through a distributed representation among different cortical areas: each area is devoted to a specific feature. Features are topologically organized (as in the conceptual model by Barsalou et al. (Barsalou et al. 2003)) and linked together by implementing two high-level Gestalt rules: similarity and previous knowledge. Multiple object retrieval is realized by means of synchronized activity of neural oscillators in the gamma-band (an idea often exploited in models for segmentation of visual or auditory scenes (von der Malsburg & Schneider 1986; Singer & Gray 1995; Wang & Terman 1997), and which reminds the conceptual Semantic Object Model by Kraut et al. (Kraut et al. 2002)). Finally, words are represented in a separate cortical area, and linked with the correct object representation via a Hebbian mechanism (Rolls & Treves 1998).

In the following, the model is first presented in a qualitative way, and some exemplary results, concerning object retrieval, connection between objects and words, and categories, are presented. All equations are reported in the Appendix. It is worth noting that the present model is significantly improved compared with previous versions (Ursino et al. 2009; Cuppini et al. 2009): the new aspects concern the possibility to represent objects with a different number of features (whereas a fixed number of features for all objects was used in previous works) and a more physiological mechanism to recognize words from objects. All new aspects are emphasized in the text.

2. Method and results

The model incorporates two networks of neurons, as illustrated in the schematic diagram of Fig. 1. These are briefly described below in a qualitative way, while all equations and parameters can be found in the Appendix.

1) *The feature network and its training* - The first network, named "feature network", is devoted to a description of objects represented as a collection of sensory-motor features. These features are assumed to spread along different cortical areas (both in the sensory and motor cortex) and are topologically organized according to a similarity principle. This means that two similar features activate proximal neural groups in the feature network.

The network is composed of *N* neural oscillators, subdivided into *F* distinct cortical areas (see Fig.1). Each area in the model is composed of $N_1 x N_2$ oscillators. An oscillator may be silent, if it does not receive enough excitation, or may oscillate in the gamma-frequency band, if excited by a sufficient input. The presence of oscillators in this network is motivated by the necessity to have different objects simultaneously in memory, each represented by its collection of features (that is the classic binding and segmentation problem). As proposed by several authors in recent years, both experimentally (Singer & Gray 1995; Engel & Singer 2001), and theoretically (von der Malsburg & Schneider 1986; Wang & Terman 1997), binding and segmentation of multiple objects can be achieved in the brain via synchronization of neural oscillators in the gamma range.

Previous works demonstrated that, in order to solve the segmentation problem, a network of oscillating units requires the presence of a "global separator" (von der Malsburg & Schneider 1986; Wang & Terman 1997; Ursino et al. 2003). For this reason, the feature network incorporates a inhibitory unit which receives the sum of the whole excitation coming from the feature network, and sends back a strong inhibitory signal if this input exceeds a given threshold. In this way, as soon as a single object representation pops out in the network, all other objects representations are momentarily inhibited, avoiding superimposition of two simultaneous objects.

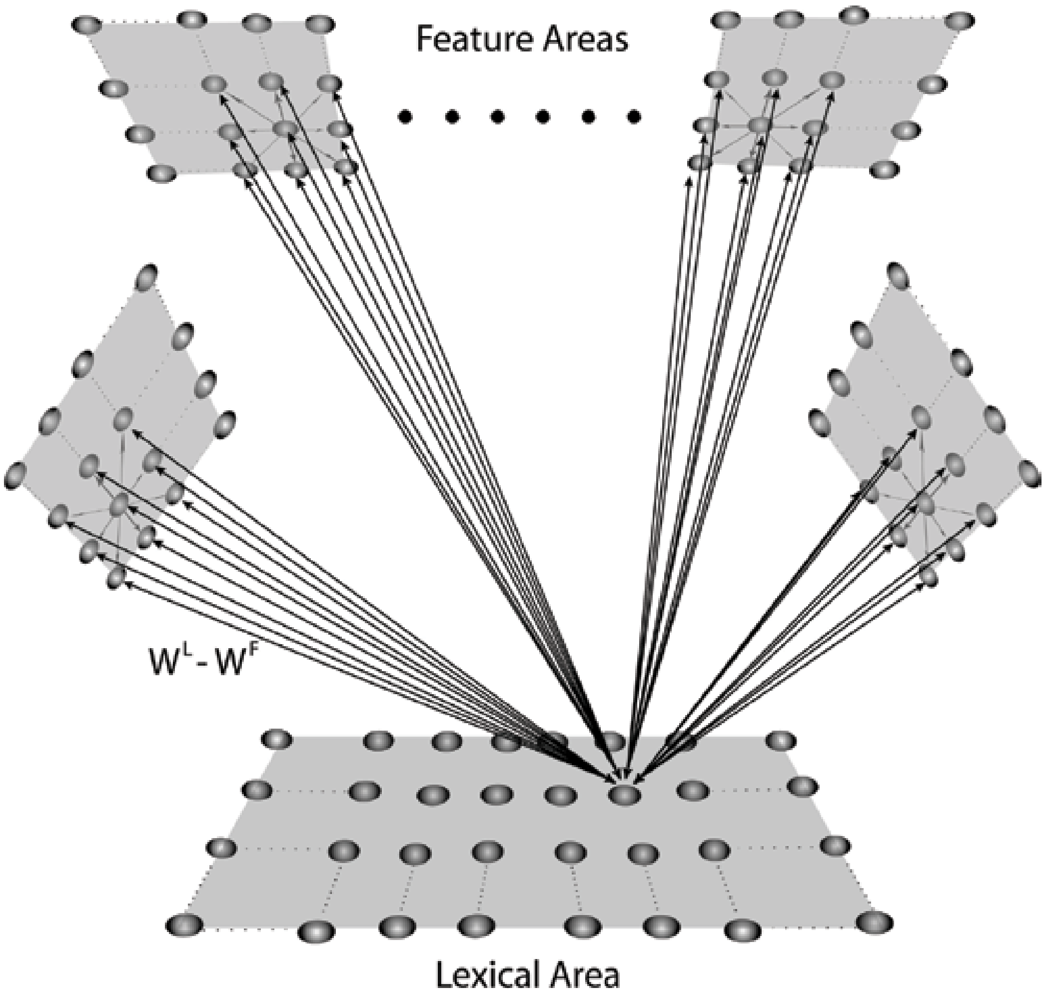

Fig. 1. Schematic diagram describing the general structure of the network. The model presents 9 distinct Feature Areas (upper shadow squares) of 20x20 elements, which are described by means of Wilson-Cowan oscillators, and a Lexical Area of 40x40 elements (lower shadow square), which are represented by a first order dynamics and a sigmoidal relationship. In the Feature network, each oscillator is connected with other oscillators in the same area via lateral excitatory and inhibitory intra-area synapses, and with other oscillators in different areas via excitatory inter-area synapses. Moreover, elements of the feature and lexical networks are linked via recurrent synapses (W^F, W^L).

During the simulation, a feature is represented by a single input localized at a specific coordinate of the network, able to trigger the oscillatory activity of the corresponding unit. We assume that these inputs are the result of upstream processing stages, that extracted the main sensory-motor properties of the objects. The way these features are extracted and represented in the sensory and motor areas is well beyond the aim of the present model.

The topological organization of each cortical area is realized assuming that each oscillator is connected with the other oscillators in the same area via lateral excitatory and inhibitory synapses (*intra-area synapses*). These are arranged according to a mexican hat disposition, i.e., proximal neurons excite reciprocally and inhibit more distal ones. This disposition produces an "activation bubble" in response to a single localized feature input: not only the neural oscillator representing that individual feature is activated, but also the proximal ones linked via sufficient lateral excitation. This has important consequences for object recognition: neural oscillators in proximal positions share a common fate during the learning procedure. In fact, since learning occurs via a Hebbian procedure (see below), neuron oscillators that are simultaneously active are subject to a common synapse reinforcement, hence participate to the representation of the same object. In this way, an object can be recognized even in the presence of a moderate alteration in some of its features.

Throughout the following simulations, we assumed that the lateral intra-area synapses cannot be modified by experience, i.e., the similarity principle they implement is assigned "a priori". This is probably not true in the reality, since topological maps can be learned via classical Hebbian mechanisms (Rolls & Treves 1998; Haykin 1999). However, this choice is convenient to maintain a clear separation between different processes in our model (i.e. the implementation of the similarity principle on one hand and implementation of a previous knowledge principle on the other).

Besides the intra-area synapses, we also assumed the existence of excitatory long-range synapses between different feature areas (*inter-area synapses*). These are initially set at zero and are learned by experience during a training phase, in which individual objects (described by all their features) are presented to the network one by one. The learning rule is a time-dependent Hebbian rule, based on the correlation between the activity in the post-synaptic unit, and the activity in the pre-synaptic unit mediated over a previous 10 ms time-window (see (Markram et al. 1997; Abbott & Nelson 2000)).

To simplify the algorithm, in previous works we assumed that each object is described by a fixed number of features (four features in (Ursino et al. 2009; Cuppini et al. 2009)). Conversely, in the present version this constraint is removed, and we assume that the number of features describing a single object can vary from one object to the next. In the following exempla, the feature network will be subdivided into nine different cortical areas. Hence, an object can have up to nine different features. This limit has been introduced just to reduce the computational weight.

An example of the synaptic changes obtained from the learning procedure is shown in Fig. 2, which depicts the synapses targeting onto a neuron. Here an object is described by means of five different features, located in five different cortical areas. After training, neurons belonging to the five activation bubbles are linked by means of excitatory connections, and synchronize their oscillatory activity. In particular, a neuron coding for a single feature of the object after training receives excitatory synapses from four different bubbles of neurons, representing the other four features of the same object and their minimal variations.

In summary, intra-area lateral connections implement a similarity principle, while inter-area trained connections implement a "previous knowledge" principle.

An important aspect of our model is that, after training, multiple objects can be simultaneously recovered in memory and oscillate in time division with their frequency in the gamma-band. Moreover, an object can be recovered even if some features are lacking, or even if some features are reasonably altered compared with those of the prototypical object used during the learning phase. Fig. 3 shows an example in which three previously trained objects, characterized by three, five and seven features respectively, are simultaneously

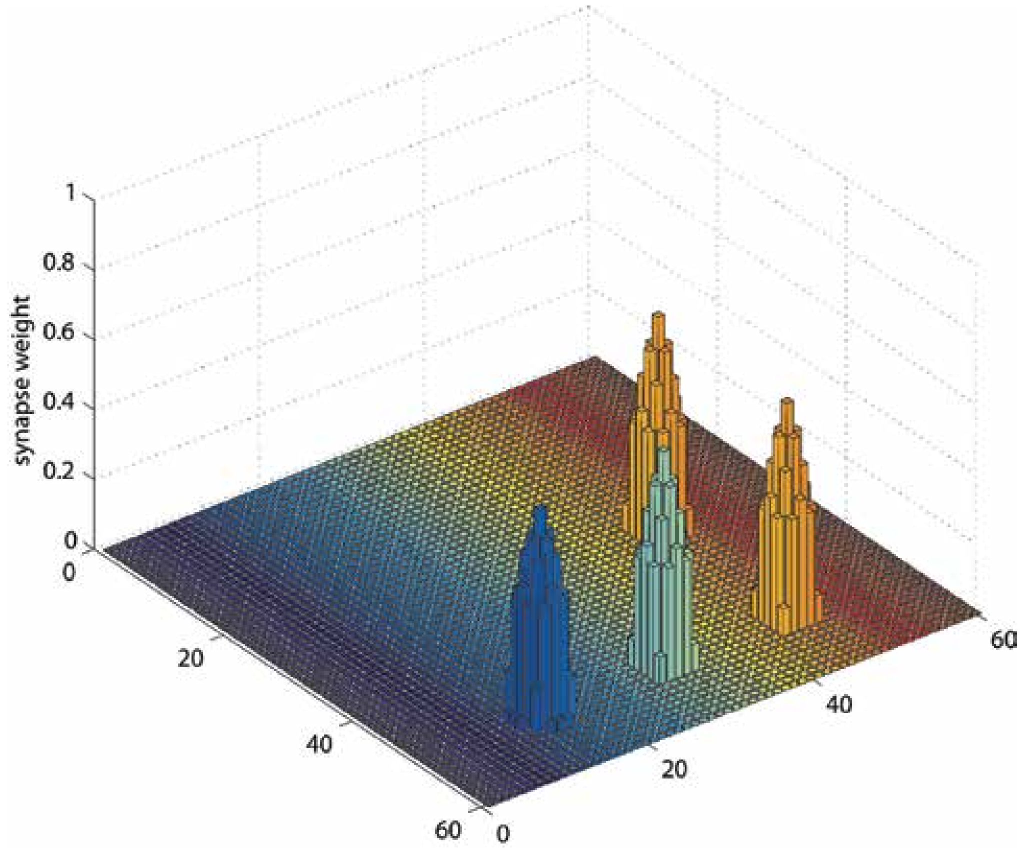

Fig. 2. An example of the inter-area synapses linking neurons in the feature areas, obtained after training a single object with five features, located at positions [50 15], [50 30], [30 30], [50 45], and [30 45]. The figure represents the synapses entering the neuron at position [30,30]. It is worth noting that this neuron, representing an individual feature of the object, receives synapses from four different bubbles, each centered at the remaining features of the object.

presented to the network. Moreover, as described in the figure legend, the objects are recovered despite the presence of incomplete information (some features are lacking) and corrupted data (some features are slightly changed).

2) *The lexical network and its training* – In order to associate objects with words, the model includes a second layer of neurons, denoted "lexical network". Each computational unit in this network codes for a word (or a lemma) and is associated with an individual object representation. Even for what concerns this network (as the previous one), the input must be considered as the result of an upstream processing stream, which recognizes the individual words from phonemes or from written texts. Description of this processing stream is well beyond the aim of this model: some exempla can be found in recent works by others (Hopfield & Brody 2001). Moreover, units in this network can also be stimulated through long-range synapses coming from the feature network; hence the network represents an amodal convergence zone, as often hypothesized in the anterior temporal lobe (Damasio 1989; Snowden et al. 2004; Ward 2006).

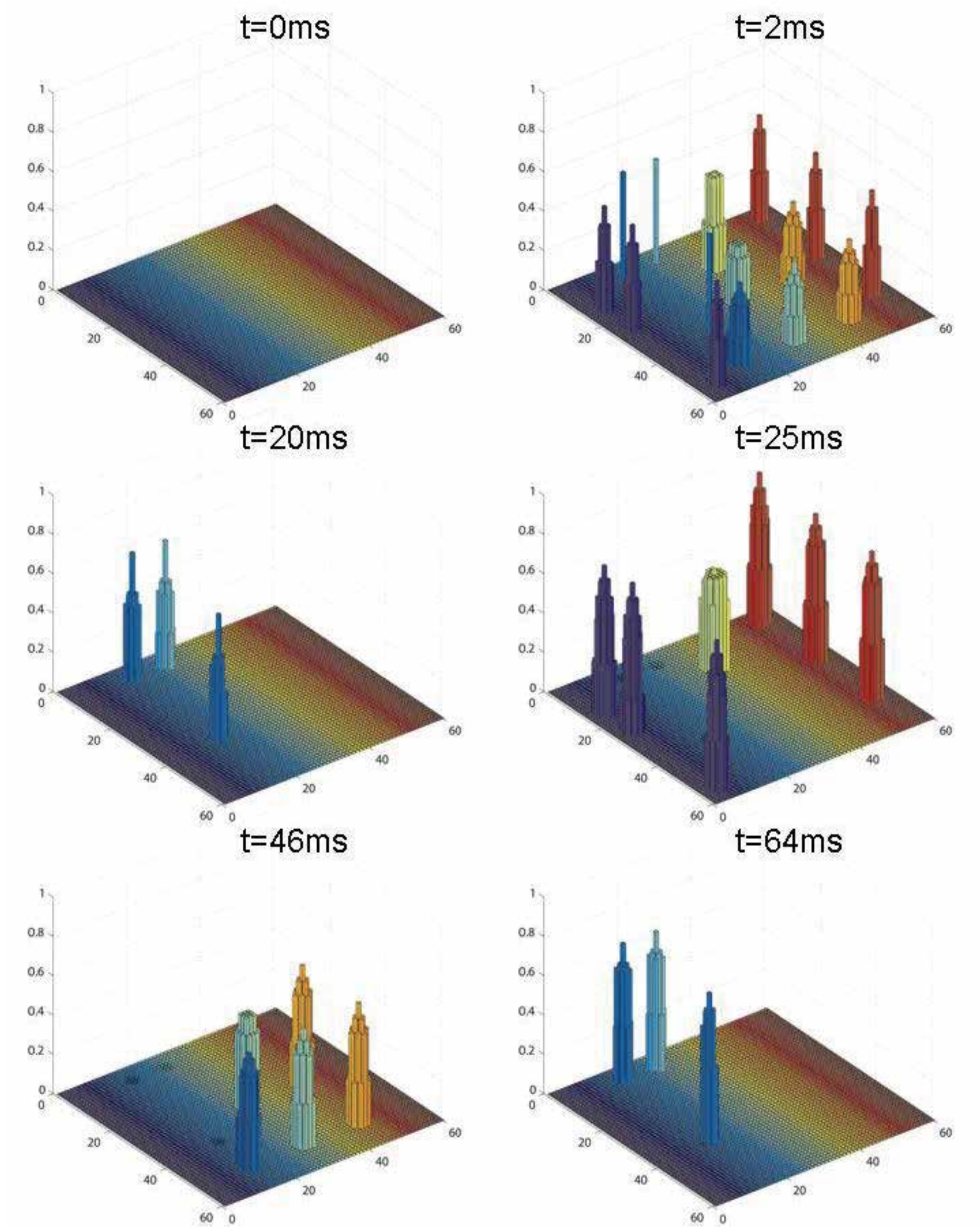

Fig. 3. Snapshots showing the activities in the feature areas at some instants of the simulation, after the presentation of three different objects: object1, three features at positions [6 17], [6 26], [37 16]; object2, five features at positions [50 15], [50 30], [30 30], [50 45], [30 45]; object 3, seven features at positions [15 5], [15 35], [55 5], [25 5], [45 55], [5 55] [25 55]. The objects were learned during a previous training phase. During the simulation, one property of the object1 was shifted compared with the normal one, while one property of both object2 and object3 was lacking. Despite this corrupted/lacking information, the network can reconstruct and segment the three objects.

For the sake of simplicity, computational units in this network are described via a simple first-order dynamics and a non-linear sigmoid relationship. Hence, if stimulated with a constant input, these units do not oscillate but, after a transient response, reach a given steady-state activation value (but, of course, they oscillate if stimulated with an oscillating input coming from the feature network).

In order to associate words with their object representation, we performed a second training phase, in which the model receives a single input to the lexical network (i.e., a single word is detected) together with the features of a previously learned object. Synapses linking the objects with words, in both directions (i.e., from the lexical network to the feature network and viceversa) are learned with Hebbian mechanisms.

While synapses from words to features ($W^{L}_{ij,hk}$ in Fig. 1) are simply excitatory and are trained on the basis of the pre and post synaptic correlation, when computing the synapses from features to words ($W^{F}_{ij,hk}$ in Fig. 1) we tried to address two major requirements, that are essential for correct object recognition. First, a word must be evoked from the corresponding object representation only if all its features are simultaneously on. This corresponds to a correct solution of the binding problem. Second, the word must not be evoked if spurious features (not originally belonging to the prototypical object) are active. This second situation may occur when two or more objects, simultaneously present, are not correctly segmented, and some of their features pop up together. Hence, the second requirement corresponds to a correct solution of the segmentation problem.

In order to address these two requirements, in previous works we implemented a complex "decision network" (see (Ursino et al. 2009)). Conversely, in the present model we adopted a more straightforward and physiologically realistic solution. First, we assumed that, before training, all units in the feature network send strong inhibitory synapses to all units in the lexical network. Hence, activation of any feature potentially inhibits all lexical units. These synapses are then progressively *withdrawn* during the training phase, on the basis of the correlation between activity in the feature unit and in the lexical unit. The consequence of this choice is that, after training, a word receives inhibition from all features that do not belong to its object representation, but no longer receives inhibition from its own feature units.

Moreover, we assume that all feature units can send excitatory synapses to lexical units: these are initially set at zero and are *reinforced* via a Hebbian mechanism. Moreover, we assumed that excitatory synapses from features to words are subject to an upper saturation level, i.e., *the sum* of all excitatory synapses reaching a lexical unit must not overcome a maximum level. This is a physiological rule, since the amount of neurotransmitter available at a neuron is limited. This rule warrants that, after prolonged training, the sum of synapses entering a lexical unit is constant, independently of the number of its associated features.

Using quite a sharp sigmoidal characteristic for lexical units, the previous two rules ensure that a word in the lexical network is excited if and only if all its features are simultaneously active: if even a single feature is not evoked, the word does not receive enough excitation (failure of the binding problem); if even a spurious feature pops up, the lexical unit receives excessive inhibition (failure of the segmentation problem): in both conditions it does not jump from the silent to the excited state.

Two exempla of model behavior are shown in Figs. 4 and 5. In the first figure, one word and two objects are simultaneously given to the network. The word evokes the corresponding object representation in the feature network, while the objects evoke the corresponding words in the lexical network. It is worth noting that all objects in the feature network oscillate in time division, and thus are all individually recognized. In the second figure, two incomplete objects are given to the feature network. The first is characterized by five features, but only four of them are given as input. However, these four features are sufficient to recover the whole object representation and the corresponding word is activated in the lexical area. Conversely, the second object is characterized by seven features, while only three features are given as input. These are insufficient to recover the overall object representation, and the corresponding word is not activated (i.e., the subject did not recognize the object starting from such an incomplete information). It is worth noting that the number of incomplete information necessary to recover the whole object depends on the strength of inter-area synapses in the feature network, hence on the duration of the previous training period. In our simulations, we always assumed that, after training, at least 50% or more of the object features are required to attain the overall object reconstruction.

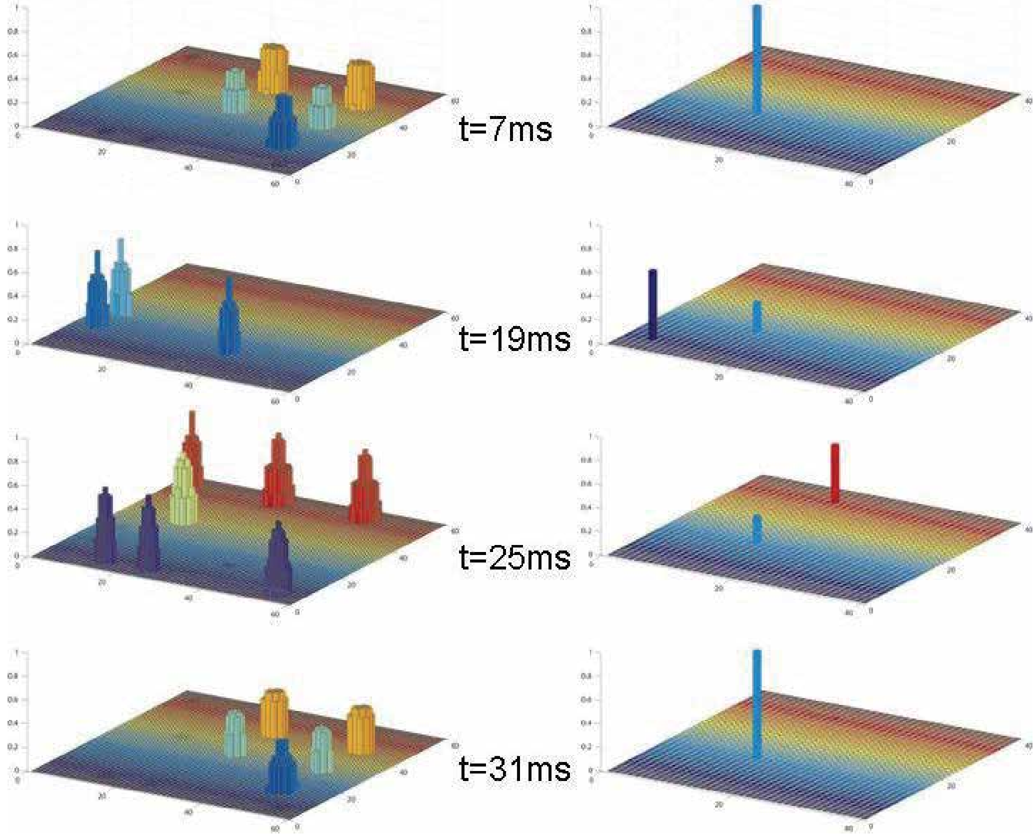

Fig. 4. Snapshots showing the activities in the feature areas (left panels) and in the lexical area (right panels) at some instants of the simulation, after the presentation of two different objects and of one word. Objects and words were previously learned during the training phases. Objects are the same as in Fig. 3. The associated words were located at position [5,5] (object1), [15,15] (object2) and [15,35] (object3). During the simulation, object1 and object3 were given as input to the feature areas, while the word2 was given as input to the lexical area. It is worth noting that the three object representations oscillate in time division in the feature areas, while the three words are evoked in the lexical area. Word2 (constantly given as input) is partially inhibited during the appearance of the other two words.

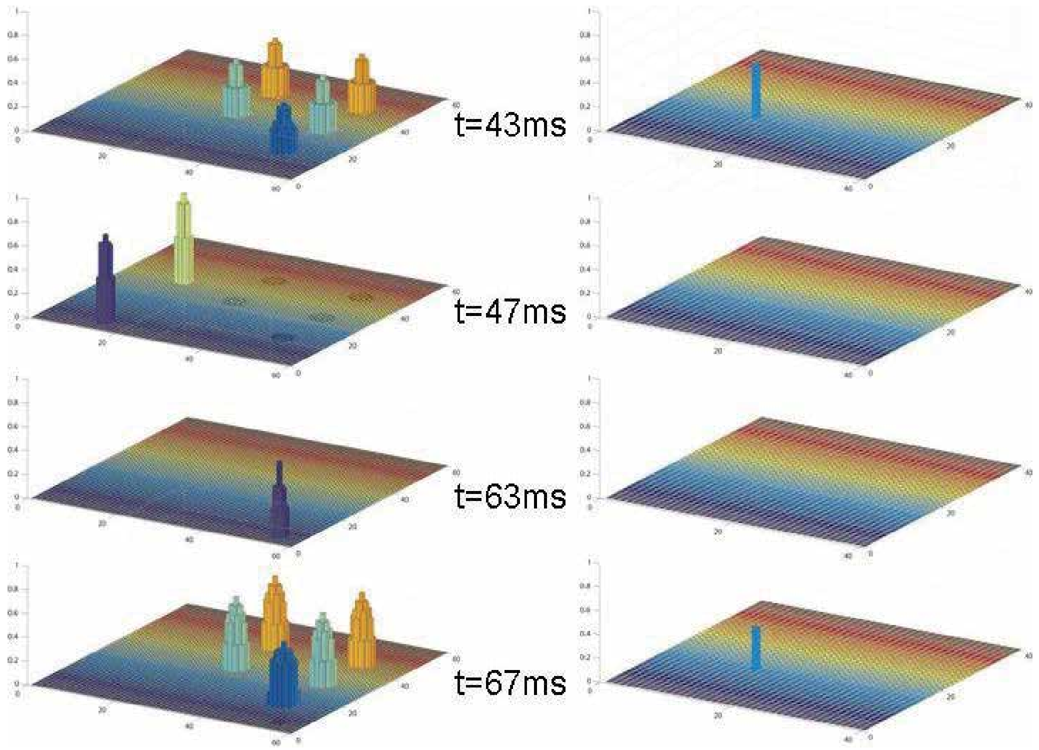

Fig. 5. Snapshots showing the activities in the feature areas (left panels) and in the lexical area (right panels) at some instants of the simulation, after the presentation of four features of object2, and just of three features of object3. As a consequence, object2 is correctly reconstructed in the feature areas, and the corresponding word is evoked in the lexical area. Conversely, object3 is not reconstructed (its three features given as input do not synchronize nor evoke the remaining four features), and the corresponding word fails to appear in the lexical area.

The structure of the model can also be used to study the formation of categories starting from a distributed representation of features. A widely shared idea, in fact, is that a category can be realized by objects which share some common features (for instance, "dog" and "cat" belong to the category "pet" and have many common characteristics). This idea is supported by experiments on the so-called "semantic priming", i.e., object recognition can be modulated by the previous recognition of another object which is "semantic congruent" (Rossell et al. 2003; Matsumoto et al. 2005). The explanation may be that the two objects activate some common neural structures, resulting in a classic priming phenomenon.

Category formation can be reproduced in our model by simply assuming objects that have some common features, and assuming that these common features are associated with a specific word, having a more general meaning (i.e., denoting a category).

Let us consider an example in which two objects (for convenience, "cat" and "dog"), with seven features each, are trained and associated with two different words. Moreover, we assumed that these two objects have four common features (representing the common characteristics of "pets"). It is worth noticing that, after the training phase 1, the inter-area synapses in the feature network are the sum of synapses learned during each object presentation. As a consequence, the four common features are linked together by means of stronger synapses compared with the remaining specific features distinguishing cats from dogs, which are more weakly linked together and to the other four features. Hence, we have an irregular pattern of synapses (Fig. 6).

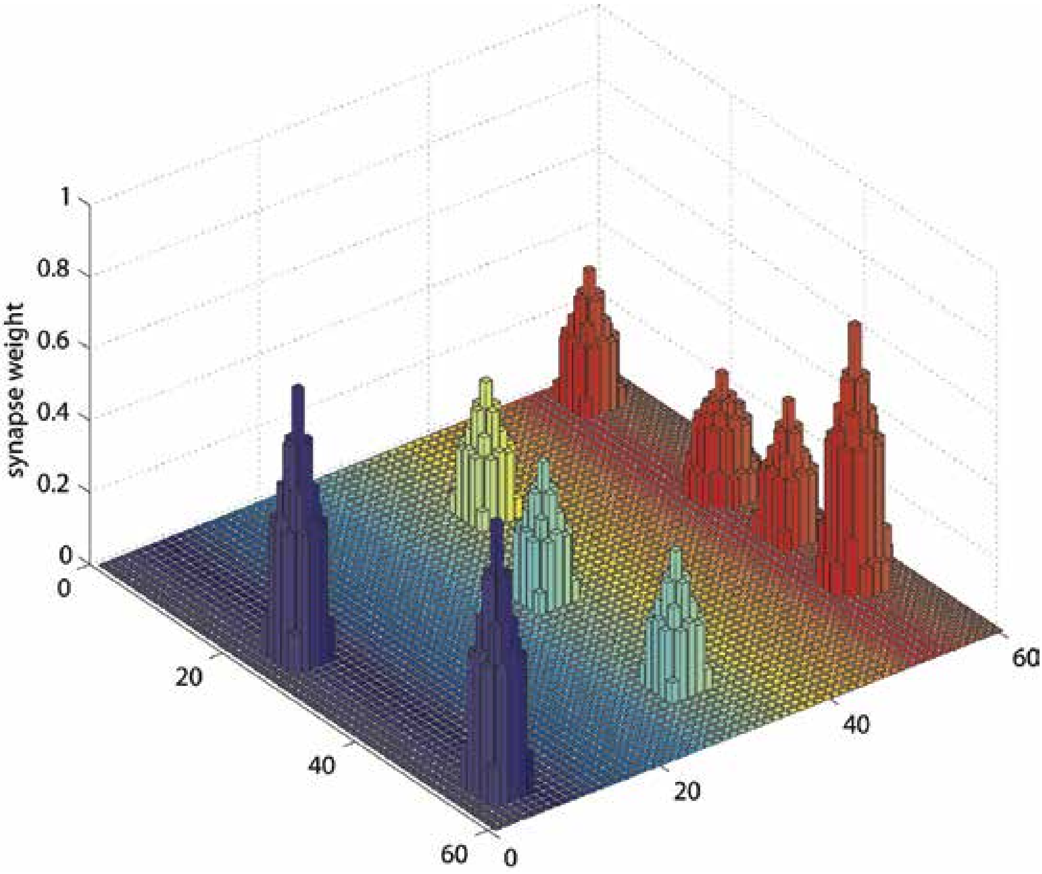

Fig. 6. An example of the inter-area synapses linking neurons in the feature areas, obtained after training two objects with a significant number of common features. In particular, the first object ("cat") has seven features located at positions [15 5], [15 35], [55 5], [25 5], [45 55], [5 55], [25 55]; the second object ("dog") has seven features at positions [15 5], [30 30], [55 5], [25 5], [45 55], [50 30], [35 55] (the first, third, fourth and fifth features are in common and may represent "pets"). The figure shows the synapses entering the neuron at position [15,5]. It is worth noting that this neuron, representing a common feature, receives synapses from nine different bubbles, each centered at the remaining features of the two objects. Three synaptic bubbles (coming from the other three common features [55 5], [25 5], [45 55]) are much stronger; other six synaptic bubbles (coming from the remaining six specific features) are weaker. The stronger synapses contribute to the category representation.

We assumed that, after the first training phase, the four common features alone are unable to recover the three remaining features (otherwise, any pet would retrieve the words "dog" and "cat"). During the second training phase, the features representing objects "dog"(7 features), "cat" (7 features) and "pet" (4 common features) were separately given to the network together with the corresponding words, to generate three distinct lexical links.

Simulation results are presented in Fig. 7. In this figure, all seven features describing a cat were initially given to the network (during the first half of the simulation). In this condition, the corresponding word is activated in the lexical area (a similar result, of course, would be obtained giving seven features of "dog" to the network). It is worth noticing that the word "pet" is not active in the lexical area, due to inhibition coming from an excessive number of features. Conversely, when the number of features given to the network is reduced to four (second part of the simulation), all belonging to the category "pet", the network does not recall the features specific of cats and dogs, and the word "pet" is now emerging in the lexical area, without the emerging of the words "dog" and "cat".

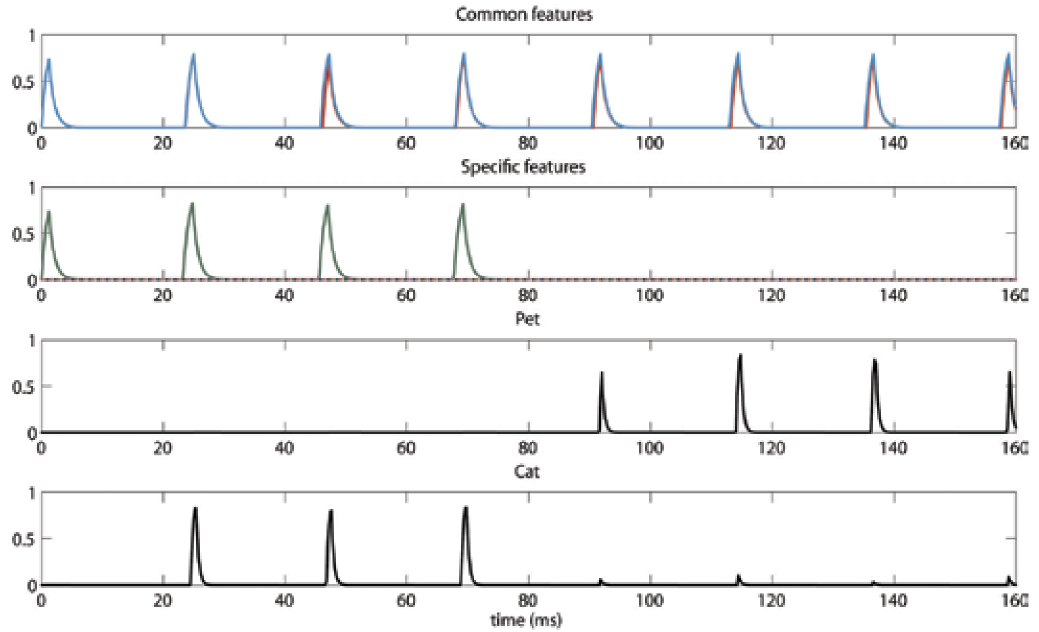

Fig. 7. Time pattern of neuron activities in the feature areas (upper panels) and in the lexical area (bottom panels) during a simulation, in which the seven features of the object "cat" (see legend of fig. 6) were given as input to the feature areas during the first 100 ms; at 100 ms, the three specific features were set at zero, and only the four common features remained as input. The upper panel shows the oscillatory activity of the four neurons in the feature areas representing the common attributes of "pets". They oscillate in synchronism throughout the simulation. The second panel represents the synchronized activities of the three neurons representing the specific attributes of cats. The third panel represents the neuron in the lexical areas coding for "pet". The fourth panel represents the activity in the lexical area of the neuron coding for "cat". It is worth noting that the word "cat" is inhibited, and the word "pet" excited, as soon as the specific features are withdrawn.

3. Discussion

The present work intends to summarize several different ideas on semantic memory, appeared in the neurocognitive and psycholinguistic literature over past years, into a coherent and

comprehensive neural network model. The main points that characterize model functioning are briefly discussed below, together with their neurophysiological support:
i) The model assumes that binding and segmentation of multiple objects occur via synchronization of neural activity in the gamma-band. This idea, originally proposed with reference to vision problems (Singer & Gray 1995; Engel & Singer 2001), is now widely supported also for what concerns high-level cognitive problems. For instance, a role of gamma-activity has been demonstrated in recognition of music (Bhattacharya et al. 2001), faces (Rodriguez et al. 1999), as well as during visual search tasks (Tallon-Baudry et al. 1997) and delayed-matching-to-sample-tasks (Tallon-Baudry et al. 1998). ii) Each object is described by means of a different number of features, which spread over different cortical areas. This is quite a common idea in conceptual models of semantic memory (Caramazza et al. 1990; Gainotti 2006; Hart et al. 2007). iii) Features are topographically organized. Results supporting this idea can be found in recent works by Barsalou et al. (Simmons & Barsalou 2003; Barsalou et al. 2003). iv) Knowledge of previous objects is stored in the model by means of inter-area synapses, which realize excitatory links learned via a Hebbian mechanism. Hence, it is sufficient that several features of an object occurred together for a sufficient long period in the past, for the creation of a permanent link. v) Words are represented in a different cortical area, separate from features. Although it is difficult to find a specific cortical location for this area, the existence of cortical regions especially devoted to lexical aspects of language has been hypothesized in cognitive neuroscience for decades (Ward 2006). vi) Links between lexical aspects (words) and semantic aspects (i.e., object representation) are learned via Hebbian mechanisms too. This requires the simultaneous presentation of an object with its representative word. vii) Objects can evoke words only if all their features have been correctly restored in memory and segmented from features of other objects. In other terms, the present model implies that a complete semantic recognition is a prerequisite for evocation of words. viii) The presentation of a word (from phonemes or from written texts) is able to evoke the representation of the object. Some recent data in the neurophysiologic literature support this idea: presentation of an action word can evoke activity in the motor and premotor cortex (Pulvermller et al. 2005a; Pulvermller et al. 2005b) and presentation of a smell can activate olfactory areas (González et al. 2006). ix) Categories can be represented by features which belong to different objects simultaneously, assuming that these shared features can be associated with a new word, and that activities of these features, when presented alone, remain bounded without spreading to reconstruct the original individual objects. x) The relationships from objects to words require the presence of both excitatory and inhibitory mechanisms, to evoke objects separately from their category, or to avoid that the presence of an excessive number of features (as in the failure of the segmentation task) evokes erroneous words.

Using the previous basic ideas, the model is able to simulate semantic memory and its link with lexical aspects in a variety of conditions which, although drastically simplified compared with the reality, can provide some cues to drive future ideas and to test the reliability of existing theories.

The present simulations (recognition of different simultaneous words and objects, even in the case of absent or corrupted features) represent just a few aspects of the potential model applications. Future challenges may be concerned with the following major issues, which have not been explicitly treated here due to space limitations:

Semantic relationships among words - An important problem that can be simulated with the model consists in the semantic priming, i.e., the possibility that a previous word or a previous object (a cue) may affect (facilitate or depress) recognition of a subsequent word or subsequent object (a target) which is “semantically congruent” (Rossell et al. 2003; Matsumoto et al. 2005). This sort of priming mechanism, which may have important implication in language, may be simulated assuming that the two semantically congruent objects share some of their activated features, and that the representation of the first object is still partly active when the second object is presented to the network.

Bilingualism - A further aspect which may be simulated with the model is the lexical organization in bilingualism. This may be simulated assuming that two words in the lexical area (i.e., a first word already learned in a native language, say L1, and a second word in a new language, say L2) are associated with the same object representation in the feature area. During the learning procedure of the second language, the L2 word may exploit the already existing links between the L1 word and the object representation, to create its own excitatory synapses. As commonly suggested in the psycholinguistic literature (Abutalebi 2008), the new language may depend on L1 to mediate access to its object representation, i.e., L2 words are generally acquired with reference to existing L1 concepts. In the final bilingual subject, however, who exhibits high proficiency for L2, managing bilingualism requires the addition of further competitive mechanisms, and sophisticate control strategies (Green 1998), which allow the selection of the chosen word (or language) by inhibiting the other one. The interested reader can consult (Green 1998; Abutalebi 2008) for conceptual theories on the subject.

Lexical deficits – The model can be used to simulate patients with category-specific lexical deficits, i.e., patients unable to recognize certain categories of objects (Warrington & McCarthy 1983; Warrington & Shallice 1984; Warrington & McCarthy 1987; Humphreys & Forde 2001). To this end, one may suppose that only synapses in certain feature areas are weakened (for instance, as a consequence of a local lesion) thus resulting in a deficit for those words and those objects only, which make an intensive use of these areas.

These last aspects are just exempla of how the model may have a large applicative domain in future research. Its validation, amelioration and extension, however, and its use for the analysis and the theoretical formalization of different semantic/lexical problems, will necessarily require a strong multidisciplinary approach. This should entrain researchers in different domains: such as neurophysiologists, cognitive neuroscientists, experts of psycholinguistics, mathematicians and neuro-engineers.

4. Appendix

4.1 The bidimensional network of features

In the following, each oscillator will be denoted with the subscripts *ij* or *hk*. In the present study we adopted an exemplary network with 9 areas (F = 9) and 400 neural groups per area ($N_1 = N_2 = 20$).

Each single oscillator consists of a feedback connection between an excitatory unit, x_{ij}, and an inhibitory unit, y_{ij} while the output of the network is the activity of all excitatory units. This is described with the following system of differential equations

$$\frac{d}{dt}x_{ij}(t) = -x_{ij}(t) + H\left(x_{ij}(t) - \beta \cdot y_{ij}(t) + E_{ij}(t) + V_{ij}^{L}(t) + I_{ij} - \varphi_x - z(t)\right) \tag{1}$$

$$\frac{d}{dt}y_{ij}(t) = -\gamma \cdot y_{ij}(t) + H\left(\alpha \cdot x_{ij}(t) - \varphi_y\right) + J_{ij}(t) \tag{2}$$

where H() represents a sigmoidal activation function defined as

$$H(\psi) = \frac{1}{1 + e^{-\frac{\psi}{T}}} \tag{3}$$

The other parameters in Eqs. (1) and (2) have the following meaning: α and β are positive parameters, defining the coupling from the excitatory to the inhibitory unit, and from the inhibitory to the excitatory unit of the same neural group, respectively. In particular, α significantly influences the amplitude of oscillations. Parameter γ is the reciprocal of a time constant and affects the oscillation frequency. The self-excitation of x_{ij} is set to 1, to establish a scale for the synaptic weights. Similarly, the time constant of x_{ij} is set to 1, and represents a scale for time *t*. φ_x and φ_y are offset terms for the sigmoidal functions in the excitatory and inhibitory units. I_{ij} represents the external stimulus for the oscillator in position *ij*, coming from the sensory-motor processing chain which extracts features. E_{ij} and J_{ij} represent coupling terms (respectively excitatory and inhibitory) from all other oscillators in the features network (see Eqs. 5-8), while V_{ij}^{L} is the stimulus (excitatory) coming from the lexical area (Eq. 9). *z(t)* represents the activity of a global inhibitor whose role is to ensure separation among the objects simultaneously present. This is described with the following algebraic equation:

$$z = \left[sign\left(\sum_i \sum_j x_{ij} - \theta_z \right) + 1 \right] \Big/ 2 \tag{4}$$

According to Eq. 4, the global inhibitor computes the overall excitatory activity in the network, and sends back an inhibitory signal ($z = 1$) when this activity overcomes a given threshold (say θ_z). This inhibitory signal prevents other objects from popping out as long as a previous object is still active.

The coupling terms between elements in cortical areas, E_{ij} and J_{ij} in Eqs. (1) and (2), are computed as follows

$$E_{ij} = \sum_h \sum_k W_{ij,hk} \cdot x_{hk} + \sum_h \sum_k L_{ij,hk}^{EX} \cdot x_{hk} \tag{5}$$

$$J_{ij} = \sum_h \sum_k W_{ij,hk} \cdot x_{hk} + \sum_h \sum_k L_{ij,hk}^{IN} \cdot x_{hk} \tag{6}$$

where *ij* denotes the position of the postsynaptic (target) neuron, and *hk* the position of the presynaptic neuron, and the sums extend to all presynaptic neurons in the feature area. The symbols $W_{ij,hk}$ represent inter-area synapses, subjects to Hebbian learning (see next paragraph), which favour synchronization. The symbols $L_{ij,hk}^{EX}$ and $L_{ij,hk}^{IN}$ represent lateral excitatory and inhibitory synapses among neurons in the same area. It is worth noting that all terms $L_{ij,hk}^{EX}$ and $L_{ij,hk}^{IN}$ with neurons *ij* and *hk* belonging to *different* areas are set to zero. Conversely, all terms $W_{ij,hk}$, linking neurons *ij* and *hk* in the *same* area, are set to zero.

The Mexican hat disposition for the intra-area connections has been realized by means of two Gaussian functions, with excitation stronger but narrower than inhibition. Hence,

$$L_{ij,hk}^{EX} = \begin{cases} L_0^{EX} e^{-\left[(i-h)^2 + (j-k)^2\right]/(2\sigma_{ex}^2)} & \text{if } ij \text{ and } hk \text{ are in the same area} \\ 0 & \text{otherwise} \end{cases} \tag{7}$$

$$L_{ij,hk}^{IN} = \begin{cases} L_0^{IN} e^{-\left[(i-h)^2+(j-k)^2\right]/(2\sigma_{in}^2)} & \text{if } ij \text{ and } hk \text{ are in the same area} \\ 0 & \text{otherwise} \end{cases} \tag{8}$$

where L_0^{EX} and L_0^{IN} are constant parameters, which establish the strength of lateral (excitatory and inhibitory) synapses, and σ_{ex} and σ_{in} determine the extension of these synapses.

Finally, the term V_{ij}^L coming from the lexical area is calculated as follows

$$V_{ij}^L = \sum_h \sum_k W_{ij,hk}^L \cdot x_{hk}^L \tag{9}$$

where x_{hk}^L represents the activity of the neuron *hk* in the lexical area and the symbols $W_{ij,hk}^L$ are the synapses from the lexical to the feature network (which are subject to Hebbian learning, see below).

4.2 The bidimensional lexical area

In the following each element of the lexical area will be denoted with the subscripts *ij* or *hk* ($i, h = 1, 2, \ldots, M_1$; $j, k = 1,2,\ldots, M_2$) and with the superscript *L*. In the present study we adopted $M_1 = M_2 = 40$. Each single element exhibits a sigmoidal relationship (with lower threshold and upper saturation) and a first order dynamics (with a given time constant). This is described via the following differential equation:

$$\tau^L \cdot \frac{d}{dt} x_{ij}^L(t) = -x_{ij}^L(t) + H^L\left(u_{ij}^L(t)\right) \quad ; \tag{10}$$

τ^L is the time constant, which determines the speed of the answer to the stimulus, and $H^L\left(u^L(t)\right)$ is a sigmoidal function. The latter is described by the following equation:

$$H^L\left(u^L(t)\right) = \frac{1}{1+e^{-\left(u^L(t)-\vartheta^L\right)p^L}}; \tag{11}$$

where ϑ^L defines the input value at which neuron activity is half the maximum (central point) and p^L sets the slope at the central point. Eq. 11 conventionally sets the maximal neuron activity at 1 (i.e., all neuron activities are normalized to the maximum).

According to the previous description, the overall input, $u_{ij}^L(t)$, to a lexical neuron in the *ij*-position can be computed as follows

$$u_{ij}^L(t) = I_{ij}^L(t) + V_{ij}^F \tag{12}$$

$I_{ij}^L(t)$ is the input produced by an external linguistic stimulation. V_{ij}^F represents the intensity of the input due to synaptic connections from the feature network; this synaptic input is computed as follows:

$$V_{ij}^F = \sum_h \sum_k W_{ij,hk}^F \cdot x_{hk} \tag{13}$$

where x_{hk} represents the activity of the neuron *hk* in the Feature Areas (see Eq. 1) and $W^{F}_{ij,hk}$ the strength of synapses. These synapses may have both an excitatory and an inhibitory component (say $W^{Fex}_{ij,hk}$ and $W^{Fin}_{ij,hk}$, respectively) which are trained in different ways (see session, "synapse training: phase 2", below). Hence, we can write

$$W^{F}_{ij,hk} = W^{Fex}_{ij,hk} - W^{Fin}_{ij,hk} \tag{14}$$

4.3 Synapses training

Phase 1: Training of inter-area synapses within the feature network

In a first phase, the network is trained to recognize objects without the presence of words.

Recent experimental data suggest that synaptic potentiation occurs if the pre-synaptic inputs precede post-synaptic activity by 10 ms or less (Markram et al. 1997; Abbott & Nelson 2000). Hence, in our learning phase we assumed that the Hebbian rule depends on the present value of post-synaptic activity, $x_{ij}(t)$, and on the moving average of the pre-synaptic activity (say $m_{hk}(t)$) computed during the previous 10 ms. We define a moving average signal, reflecting the average activity during the previous 10 ms, as follows

$$m_{hk}(t) = \frac{\sum_{m=0}^{N_s-1} x_{hk}(t - mT_S)}{N_s} \tag{15}$$

where T_S is the sampling time (in milliseconds), and N_S is the number of samples contained within 10 ms (i.e., $Ns = 10/T_S$). The synapses linking two neurons (say *ij* and *hk*) are then modified as follows during the learning phase

$$\Delta W_{ij,hk}(t + T_S) = W_{ij,hk}(t) + \beta_{ij,hk} \cdot x_{ij}(t) \cdot m_{hk}(t) \tag{16}$$

where $\beta_{ij,hk}$ represents a learning factor.

In order to assign a value for the learning factor, $\beta_{ij,hk}$, in our model we assumed that inter-area synapses cannot overcome a maximum saturation value. This is realized assuming that the learning factor is progressively reduced to zero when the synapse approaches its maximum saturation. Furthermore, neurons belonging to the same area cannot be linked by a long-range synapse. We have

$$\beta_{ij,hk} = \begin{cases} \beta_0 \left(W_{\max} - W_{ij,hk}\right) & \text{if } ij \text{ and } hk \text{ belong to different areas} \\ 0 & \text{otherwise} \end{cases} \tag{17}$$

where W_{max} is the maximum value allowed for any synapse, and $\beta_0 W_{\max}$ is the maximum learning factor (i.e., the learning factor when the synapse is zero).

Phase 2: Training of long-range synapses among the Lexical and the Feature Networks

These synapses are trained during a second phase, in which an object is presented to the network together with its corresponding word.

Synapses from the lexical network to the feature network (i.e., parameters $W^{L}_{ij,hk}$ in Eq. 9) are learned using an Hebbian rule similar to that used in Eqs. 16 and 17. We can write

$$W^{L}_{ij,hk}(t + T_S) = W^{L}_{ij,hk}(t) + \beta^{L}_{ij,hk} \cdot x_{ij}(t) \cdot m^{L}_{hk}(t) \tag{18}$$

where $\beta^{L}_{ij,hk}$ represents the learning factor and $m^{L}_{hk}(t)$ is the averaged signal:

$$m^{L}_{hk}(t) = \frac{\sum_{m=0}^{N_s-1} x^{L}_{hk}(t - mT_s)}{N_s} \tag{19}$$

$$\beta^{L}_{ij,hk} = \beta^{L}_{0}\left(W^{L}_{\max} - W^{L}_{ij,hk}\right) \tag{20}$$

Conversely, synapses from the feature network to the lexical network (i.e., parameters $W^{F}_{ij,hk}$ in Eq. 13) include both excitatory and inhibitory contributions:

$$W^{F}_{ij,hk}(t) = W^{Fex}_{ij,hk}(t) - W^{Fin}_{ij,hk}(t) \tag{21}$$

The excitatory portion is trained (starting from initially null values) using equations similar to 16 and 17, but assuming that the *sum* of synapses entering a word must not overcome a saturation value (say W^{Fex}_{sumMax}). Hence

$$W^{Fex}_{ij,hk}(t + T_S) = W^{Fex}_{ij,hk}(t) + \beta^{Fex}_{ij,hk} \cdot x^{L}_{ij}(t) \cdot m_{hk}(t) \tag{22}$$

$$\beta^{Fex}_{ij,hk} = \beta^{Fex}_{0}\left(W^{Fex}_{sumMax} - \sum_{lm} W^{Fex}_{ij,lm}\right) \tag{23}$$

where the average activity $m_{hk}(t)$ is defined as in Eq. 15, and the sum in the right-hand member of Eq. 23 is extended to all synapses from the feature network entering the neuron *ij* in the lexical network.

The inhibitory synapses start from a high value (say W^{Fin}_{Max}) and are progressively withdrawn using an Hebbian mechanism:

$$W^{Fin}_{ij,hk}(t + T_S) = [W^{Fin}_{ij,hk}(t) - \beta^{Fin}_{ij,hk} \cdot x^{L}_{ij}(t) \cdot m_{hk}(t)]^{+} \tag{24}$$

where the function "positive part" ($[]^{+}$) is used in the right hand member of Eq. 24 to avoid that these synapses become negative (i.e., that inhibition is converted to excitation).

5. References

Abbott, L. F., and Nelson, S. B. (2000). Synaptic plasticity: taming the beast. *Nat. Neurosci.*, 3, 1178-1183.

Abutalebi, J. (2008). Neural aspects of second language representation and language control. *Acta Psychologica*, 128(3), 466-478.

Barsalou, L. W., Simmons, W. K., Barbey, A. K., and Wilson, C. D. (2003). Grounding conceptual knowledge in modality-specific systems. *Trends Cogn Sci*, 7(2), 84-91.

Bhattacharya, J., Petsche, H., and Pereda, E. (2001). Long-range synchrony in the gamma band: role in music perception. *J. Neurosci.*, 21, 6329-6337.

Caramazza, A., Hillis, A., and Rapp, B. (1990). The multiple semantics hypothesis: Multiple confusions? *Cognitive Neuropsychology*, 7, 161-189.

Caramazza, A., and Shelton, J. R. (1998). Domain-specific knowledge systems in the brain the animate-inanimate distinction. *J. Cogn. Neurosci.*, 10, 1-34.

Cuppini, C., Magosso, E., and Ursino, M. (2009). A neural network model of semantic memory linking feature-based object representation and words. *BioSystems*, 96(3), 195-205.

Damasio, A. R. (1989). Time-locked multiregional retroactivation: a systems level proposal for the neural substrates of recall and recognition. *Cognition*, 33, 25-62.

Devlin, J. T., Gonnerman, L. M., Andersen, E. S., and Seidenberg, M. S. (1998). Category-specific semantic deficits in focal and widespread brain damage: a computational account. *J Cogn Neurosci*, 10(1), 77-94.

Engel, A. K., and Singer, W. (2001). Temporal binding and the neural correlates of sensory awareness. *Trends Cogn Sci*, 5(1), 16-25.

Gainotti, G. (2006). Anatomical functional and cognitive determinants of semantic memory disorders. *Neuroscience and Behavioral Reviews*, 30, 577-594.

González, J., Barros-Loscertales, A., Pulvermller, F., Meseguer, V., Sanjun, A., Belloch, V., and Avila, C. (2006). Reading cinnamon activates olfactory brain regions. *Neuroimage*, 32(2), 906-912.

Green, D. W. (1998). Mental control of the bilingual lexico-semantic system. *Bilingualism: language and cognition*, 1(2), 67-81.

Hart, J., Anand, R., Zoccoli, S., Maguire, M., Gamino, J., Tillman, G., King, R., and Kraut, M. A. (2007). Neural substrates of semantic memory. *J Int Neuropsychol Soc*, 13(5), 865-880.

Hart, J., Moo, L. R., Segal, J. B., Adkins, E., and Kraut, M. (2002). "Neural substrates of semantics." *Handbook of language disorders*, Psychology Press, Philadelphia.

Haykin, S. (1999). "Neural Neworks: a comprehensive foundation." Prentice Hall.

Hopfield, J. J., and Brody, C. D. (2001). What is a moment? Transient synchrony as a collective mechanism for spatiotemporal integration. *Proc Natl Acad Sci U S A*, 98(3), 1282-1287.

Humphreys, G. W., and Forde, E. M. E. (2001). Hierarchies, similarity, and interactivity in object recognition: "Category-specific" neurophysiological deficits. *Behavioral and Brain Sciences*, 24, 453-509.

Kraut, M. A., Kremen, S., Segal, J. B., Calhoun, V., Moo, L. R., and HArt, J. (2002). Object activation from features in the semantic system. *J Cogn Neurosci*, 14(1), 24-36.

Lambon Ralph, M. A., Lowe, C., and Rogers, T. T. (2007). Neural basis of category-specific demantic deficits for living things: evidence from semantic dementia, HSVE and a neural network model. *Brain*, 130, 1127-1137.

Lauro-Grotto, R., Reich, S., and Visadoro, M. (1997). "The computational role of conscious processing in a model of semantic memory." *Cognition, Computation and Consciousness*, M. Ito, S. Miyashita, and E. Rolls, eds., Oxford University Press, Oxford, 249-263.

Markram, H., Lübke, J., Frotscher, M., and Sakmann, B. (1997). Regulation of synaptic efficacy by coincidence of postsynaptic APs and EPSSs. *Science*, 275, 213-215.

Martin, A., and Chao, L. L. (2001). Semantic memory and the brain: structure and processes. *Curr. Opin. Neurobiol.*, 11(2), 194-201.

Matsumoto, A., Iidaka, T., Haneda, K., Okada, T., and Sadato, N. (2005). Linking semantic priming effect in functional MRI and event-related potentials. *Neuroimage*, 24(3), 624-634.

McRae, K., de Sa, V. R., and Seidenberg, M. S. (1997). On the nature and scope of featural representations of word meaning. *J Exp Psychol Gen*, 126(2), 99-130.

Morelli, A., Lauro, G. R., and Arecchi, F. T. (2006). Neural coding for the retrieval of multiple memory patterns. *BioSystems*, 86(1-3), 100-109.

Pulvermller, F., Hauk, O., Nikulin, V. V., and Ilmoniemi, R. J. (2005a). Functional links between motor and language systems. *Eur J Neurosci*, 21(3), 793-797.

Pulvermller, F., Shtyrov, Y., and Ilmoniemi, R. (2005b). Brain signatures of meaning access in action word recognition. *J Cogn Neurosci*, 17(6), 884-892.

Rodriguez, E., George, N., Lachaux, J. P., Martinerie, J., Renault, B., and Varela, F. J. (1999). Perception's shadow: long-distance synchronization of human brain activity. *Nature*, 397, 430-433.

Rogers, T. T., Lambon Ralph, M. A., Garrard, P., Bozeat, S., McClelland, J. L., Hodges, J. R., and Patterson, K. (2004). Structure and deterioration of semantic memory: a neuropsychological and computational investigation. *Psychol Rev*, 111(1), 205-235.

Rolls, E. T., and Treves, A. (1998). "Neural Networks and Brain Function." Oxford University Press, Oxford.

Rossell, S. L., Price, C. J., and Nobre, A. C. (2003). The anatomy and time course of semantic priming investigated by fMRI and ERPs. *Neuropsychologia*, 41(5), 550-564.

Simmons, W. K., and Barsalou, L. W. (2003). The similarity-in-topography principle: reconciling theories of conceptual deficits. *Cogn. Neuropsychol.*, 20, 451-486.

Singer, W., and Gray, C. M. (1995). Visual Feature integration and the temporal correlation hypothesis. *Ann. Rev. Neurosci.*, 18, 555-586.

Small, S. L., HArt, J., Nguyen, T., and Gordon, B. (1995). Distributed representations of semantic knowledge in the brain. *Brain*, 118 (Pt 2), 441-453.

Snowden, J. S., Thompson, J. C., and Neary, D. (2004). Knowledge of famous faces and names in semantic dementia. *Brain*, 127, 860-872.

Tallon-Baudry, C., Bertrand, O., Delpuech, C., and Pernier, J. (1997). Oscillatory gamma-band (30-70 Hz) activity induced by a visual search task in humans. *J. Neurosci.*, 17, 722-734.

Tallon-Baudry, C., Bertrand, O., Peronnet, F., and Pernier, J. (1998). Induced gamma-band activity during the dealy of a visual short-term memory task in humans. *J. Neurosci.*, 18, 4244-4254.

Tulving, E. (1972). "Episodic and semantic memory." *Organisation of memory*, E. Tulving, and W. Donaldson, eds., Academic Press, New York.

Tyler, L. K., Moss, H. E., Durrant-Peatfield, M. R., and Levy, J. P. (2000). Conceptual structure and the structure of concepts: a distributed account of category-specific deficits. *Brain Lang*, 75(2), 195-231.

Ursino, M., La Cara, G. E., and Sarti, A. (2003). Binding and segmentation of multiple objects through neural oscillators inhibited by contour information. *Biol. Cybern.*, 89, 56-70.

Ursino, M., Magosso, E., and Cuppini, C. (2009). Recognition of abstracts objects via neural oscillators: interaction among topological organization, associative memory and gamma-band synchronization. *IEEE Tr. Neural Networks*, 20(2), 316-335.

Ursino, M., Magosso, E., La Cara, G. E., and Cuppini, C. (2006). Object segmentation and recovery via neural oscillators implementing the similarity and prior knowledge gestalt rules. *BioSystems*, 85, 201-218.

von der Malsburg, C., and Schneider, W. (1986). A neural cocktail-party processor. *Biol. Cybern.*, 54, 29-40.

Wang, D., and Terman, D. (1997). Image Segmentation based on oscillatory correlation. *Neural Computation*, 9, 805-836.

Ward, J. (2006). "The student's guide to cognitive neuroscience." Psychology Press, Hove and New York.

Warrington, E. K., and McCarthy, R. (1983). Category specific access dysphasia. *Brain*, 106, 859-878.

Warrington, E. K., and McCarthy, R. (1987). Categories of knowledge: further fractionations and an attempted integration. *Brain*, 110, 1273-1296.

Warrington, E. K., and Shallice, T. (1984). Category specific semantic impairements. *Brain*, 107, 829-854.

8

Genetics of Cognition-What can Developmental Disorders Teach Us?

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1. Introduction

Unprecedented progress in the field of genetics and genomics has offered the opportunity to explore the human brain to a larger extend than ever before. Especially the acquisition, coding, storage, recall, and decoding of information that form the response to an ever-changing environment are very active areas of research. The sequencing of the entire human genome and the description of inter-individual genomic variations ranging from single base pair changes to large-scale structural variations allow to link individual differences in cognitive ability to genomic changes, therefore advancing our understanding of information processing, storage, learning and memory (Subramanian et al., 2001).

In recent years, a major advancement in cognitive neuroscience in recent years has been the discovery of germline mutations in genes of the ras-induced mitogen-activated protein kinase (RAS/MAPK) signalling cascade, a unique signalling pathway transmitting signals from cell surface receptors to the nucleus with subsequent changes in gene transcription. A group of individuals affected with developmental disorders and variable degrees of cognitive impairment, who shared additional abnormalities in other body systems, have been instrumental to this process (Tidyman & Rauen, 2008; Tidyman & Rauen, 2009). Individuals with Noonan syndrome, LEOPARD syndrome, Costello syndrome, Cardio-Facio-Cutaneous syndrome, and Neurofibromatosis (NF1) have clinical symptoms in a number of body systems, including variable abnormalities in learning and memory. Cardiac malformations, skeletal abnormalities, skin manifestations, an increased risk for cancer, and characteristic facial features are often found in individuals affected with these rare genetic syndromes. Even though each syndrome represents a unique clinical entity that can be differentiated based on the combination of clinical symptoms and disease course, they also share a number of overlapping symptoms suggesting that these syndromes could be causally related disorders. The majority of individuals affected with these syndromes were found to have rare mutations in a variety of genes that could be linked to the RAS/MAPK signalling pathway. The identification of unique mutations in each disorder ultimately shed some light on the pathophysiology of the neuro-cardio-facial-cutaneous syndrome family. These rare Mendelian developmental disorders are instructive example for the successful application of classical genetic linkage studies, positional focused sequencing approaches, and candidate gene approaches in combination with detailed phenotyping that eventually led to the discovery of a neurophysiological system that might play a key role in cognitive and developmental processes.

Developmental disorders with cognitive disabilities in general are common, affecting about 1-2% of the population; however, the identification of the underlying genetic cause is hindered by the heterogeneity of the disorders. Many different genetic and environmental causes could potentially lead to the rather non-specific symptom of cognitive impairment. Genetic mutations that have been identified in some affected individuals are usually rare and may constitute new changes that have not been inherited from the parents. This makes the identification of underlying genetic factors difficult. Large-scale genetic mapping techniques, such as genome-wide association studies or linkage analysis in a large number of families are impractical under these scenarios. In the neuro-cardio-facio-cutaneous syndromes, it took the careful delineation of the clinical phenotype of the patients, prior knowledge of signalling pathways, and knowledge of genomic variance to link the phenotype to specific genomic variants. Researchers focussing on x-linked mental retardation took a different approach (Tarpey et al., 2009). Direct sequencing of all coding regions on the X chromosome in a heterogeneous group of families, in which mental retardation was inherited in an X-linked mode, led to the discovery of new genes involved in mental retardation. Nevertheless, much more inter-individual genomic variability was discovered than ever expected and a large proportion of this variability was found not to be related to mental retardation.

The progress in the field of mental retardation research can be helpful in understanding what to expect and how to approach other common mental disorders such as schizophrenia and mood disorders. In these conditions progress has been less impressive. Developmental syndromes, non-syndromic mental retardation, and psychiatric disorders share many common features, sometimes even overlapping symptoms. In this article, we will try to explore and compare approaches to brain function in different but intimately related disciplines of research and to open up ways for new approaches to the complexity of the brain. Great progress has been made in understanding the function of the brain and much more will be learned now that direct sequencing of single individuals is within reach as a cost-effective approach to the study of inter-individual genomic variation. However, it also has become clear that an overly simplistic understanding of the relationship between genomic variation and physiological consequences is questionable (Raymond et al., 2009).

2. The RAS/MAPK signalling cascade

The identification of mutations in proteins linked to the RAS/MAPK cascade in individuals with severe impairment of cognitive functions has led to the discovery of a signal pathway that appears to play a central role in cognitive development (Figure 1) (Aoki et al., 2008). Through cascading protein phosphorylations, information is transmitted from the cell surface to the cell nucleus leading to long lasting changes in cell metabolism and cell growth (Hancock, 2003). A key component of the RAS/MAPK signalling pathway is a family of small G-protein coupled molecules known as the RAS kinase family. These molecules, which have been implemented in cancer (Gibbs et al., 1984), transition between two functional states, an inactive form, which is bound to guanine-dinucleotide-phosphate (GDP) and an active form, which is bound to guanine-trinucleotide-phosphate (GTP). The transition between the inactive and the active state is facilitated by guanine-nucleotide-exchange factors (GEFs), whereas the transition from the active state back to the inactive state is catalyzed through GTPase-stimulating proteins (GAPs). The RAS GTPase activity can be stimulated among others by tyrosine kinase-coupled growth factor receptors. The tyrosine kinase recruits a docking protein, for example growth factor receptor-bound protein 2 (GRB2) or Src-homology-2-containing tyrosine phosphatase (SHP-2), which is the protein product of the gene tyrosine-protein phosphatase non-receptor type 11 (*PTPN11)*. The tyrosine kinase/SHP-2 complex subsequently activates the GEF proteins, which then transform RAS from its inactive to its active state. Activation of RAS proteins leads to the recruiting of Raf kinases, for example CRAF, encoded by the gene v-raf-1 murine leukemia viral oncogene homologue 1 (*RAF1)* and v-raf murine sarcome viral oncogene homologue B1 (BRAF) to the membrane. This event leads to the subsequent phosphorylation of the first member of the RAS/MAPK cascade, which starts a phosphorylation cascade of kinases, including the dual specificity mitogen-activated protein kinase kinase 1/2 (MEK1/MEK2), the MAP kinase kinase (MAP2Ks), and the extracellular signal-regulated kinase 1/2 (ERK1/ERK2), also known as MAP kinases (MAPKs). Activated ERK1 and ERK2 phosphorylate both nuclear and cytosolic substrates, connecting the cell surface receptors to nuclear transcription factor complexes and signalling molecules in the cytoplasm (Yoon & Seger, 2006). The ribosomal S6-kinase 2 (RSK2) is one of those proteins that connect the RAS/MAPK cascade to the cAMP response-element (CRE) binding (CREB) protein, a transcriptional regulator. Subsequent changes in gene expression lead to long lasting alterations in cell metabolism, cell growth and mobility. In the brain, alterations in synaptic strength, changes in the electric properties of the cell membrane, increase in the responsiveness to neurotransmitters, and even changes in the number and size of synapses have been observed (Weeber et al., 2002). In addition to tyrosine-kinase bound growth factor receptors, this cascade can also be activated through other mechanisms. Phospholipase C (PLC) and phosphokinase C (PKC) can activate RAS and provide links to neurotransmitter pathways of metabotropic glutamate receptors, acetylcholine (ACH), and serotonin receptors.

3. The neuro-cardio-facio-cutaneous syndrome family

Several excellent recent reviews of the neuro-cardio-facio-cutaneous syndromes and their underlying genetic risk factors have recently been published (Tidyman & Rauen, 2008; Tidyman & Rauen, 2009). Therefore, only a brief overview summarizing the clinical features and mutations found in these syndromes will be given in this text.

3.1 Noonan syndrome

Noonan syndrome (MIM 163950) is an autosomal dominant disorder with characteristic craniofacial features, congenital heart defects, and short stature. Ophthalmological abnormalities, musculoskeletal and cutaneous anomalies are common in these patients as well (Noonan, 1968; Shaw et al, 2007). Impairment in cognitive functions, such as learning and memory, is a variable symptom and occurs only in about 25-30% of individuals with this syndrome (Lee et al., 2005). Genetic linkage studies have mapped this disorder to a region on chromosome 12. Subsequently, mutations in the coding region of the gene *PTPN11*, located on chromosome 12q24.13, were found in patients with Noonan syndrome by positional sequencing of candidate genes in the region (Tartaglia et al., 2001). *PTPN11* encodes the protein tyrosine phosphatase SHP-2, which is an initiator of the RAS/MAPK signalling cascade (Figure 1). Mutations in *PTPN11* led to structural and functional changes in SHP-2, and therefore, an involvement of the gene in the pathophysiology of Noonan syndrome appeared likely. Soon, however, it became clear that missense mutations in this gene could explain only a portion of the cases clinically diagnosed with Noon syndrome indicating genetic heterogeneity (Tartaglia et al., 2001). Subsequently, mutations in the coding regions of other genes involved in the RAS/MAPK pathway were found. Sequencing of candidate genes identified mutations in the genes son of sevenless homolog 1 (*SOS1)* (Roberts et al., 2007; Tartaglia et al., 2007), v-raf-1 murine leukaemia viral oncogene homolog 1 (*Raf1)* (Pandit et al., 2007; Razzaque et al., 2007), and Kirsten rat sarcoma viral oncogene homolog (*KRAS)* (Schubbert et al., 2006; Zenker et al., 2007). Even though the most frequent genetic cause of Noonan syndrome is a mutation in the gene PTPN11, individual mutations are rare and scattered throughout several coding regions of the gene prohibiting a simple predictive genetic test. All known mutations affect the stability of the inactive form of the protein leading to a gain of function and increased signalling activity through the RAS/MAPK phosphorylation cascade. A simple genotype/phenotype correlation has not been feasible. Especially cognitive impairment is variable in this syndrome and not linked to a specific mutation. A recent comparison of patients with mutations in the genes *PTPN11* and *SOS1*, however, indicated that learning disabilities were absent in patients with mutations in *SOS1* (Pierpont et al., 2009), whereas cognitive impairments were common among individuals with *PTPN11* mutations and those with unknown mutation status. In addition to the effect of specific mutations, individual specific genetic background, gene-gene interactions, and compensatory mechanisms might account for the variability in the phenotype (Tartaglia et al., 2002).

3.2 LEOPARD syndrome

LEOPARD syndrome (MIM 151100) is an allelic disorder to Noonan syndrome, because it is caused by mutations in the same genes, *PTPN11* and *RAF1* (Digilio et al., 2002; Legius et al., 2002; Pandit et al., 2007). In LEOPARD syndrome the functional consequence of mutations in *PTPN11* is a loss of function instead of the gain of function usually found in Noonan syndrome. LEOPARD syndrome is characterized by cutaneous changes (**L**entigines), **E**KG abnormalities, **o**cular abnormalities, **p**ulmonary valve stenosis, **a**bnormal genitalia, **r**etardation of growth, and **d**eafness. The clinical phenotype of the affected individuals is quite similar to Noonan syndrome despite opposite effects of the mutations on the function of the protein.

3.3 Costello syndrome

In 1971, Costello described a new genetic syndrome with characteristic facial features, ectodermal anomalies, especially nasal papillomas, and developmental delay (Costello, 1971; Costello, 1977). Subsequently, extensive reviews have summarized findings in similarly affected individuals and have delineated the clinical phenotype now known as Costello syndrome (MIM 218040). Even though this genetic syndrome is clearly distinct from Noonan syndrome, both syndromes share some overlapping features (Hennekam, 2003). Individuals affected with Costello syndrome have more severe cognitive impairment than individuals affected with Noonan syndrome (Axelrad et al., 2007; Delrue et al., 2003). Search for mutations in genes of the RAS/MAPK signalling pathway led to the identification of a variety of mutations in the gene v-Ha-ras Harvey rat sarcoma viral oncogene homologue (*HRAS)* (Aoki et al., 2005; van Steensel et al., 2006; Zampino et al., 2007). The functional consequences of these mutations are increased HRAS activity and an increase in signalling through the RAS/MAPK pathway. The phenotype in patients with Costello syndrome is variable even with identical mutations in *HRAS* (Gripp et al., 2006; Kerr et al., 2006).

3.4 Cardio-facio-cutaneous syndrome

Cardio–facio–cutaneous (CFC) syndrome (MIM 214080) is characterized by distinct facial features resembling Noonan syndrome; ectodermal abnormalities, musculo-skeletal findings, and cardiac malformations. Ocular symptoms are frequently present as well (Reynolds et al., 1986, Borradori & Blanchet-Bardon, 1993; Wieczorek et al., 1997; Young et al., 1993; Grebe & Clericuzio, 2000; Sabatino et al., 1997; Herman & McAlister, 2005; Chan et al, 2002). Many features of this syndrome are overlapping with Noonan syndrome causing diagnostic uncertainty especially in young infants. However, in contrast to Noonan syndrome, cognitive impairment is universally present in patients with CFC syndrome (Yoon et al., 2007). Ultimately, the identification of a wide variety of mutations in the gene *BRAF* helped to clarify the diagnostic uncertainties (Rauen, 2006; Schulz et al., 2008; Narumi et al., 2007; Nava et al., 2007; Gripp et al., 2007). Mutations in three other related genes, *MAP2K1, MAP2K2* (Rodriguez-Viciana et al., 2006) and Ki-ras2 Kisten rat sarcoma viral oncogene homologue *(KRAS)* (Schubbert et al. 2006; Niihori et al., 2006) have also been identified in patients with CFC syndrome.

3.5 Neurofibromatosis

Neurofibromatosis (NF1) is clinically quite distinct from the neuro-cardio-facio-cutaneous syndrome family. NF1 occurs in about 1 in 4,000 birth and is characterized by the development of benign neurofibromas of the peripheral nervous system and skin discolorations (Riccardi, 1981). Gliomas of the peripheral nerves and skeletal dysplasias can occasionally occur. Mild cognitive impairment manifested as learning disability is present in about 40% to 60% of patients. Neurofibromatosis is characterized by incomplete penetrance, which means that even if an individual carries a disease-causing mutation the expression of the disease phenotype is highly variable. The identification of mutations in the gene neurofibromin shed light on possible underlying pathomechanisms in this disorder (Viskochil et al., 1990; O'Connell et al., 1992). Neurofibromin is a GAP protein, which transforms activated RAS protein back to the inactive state. The neurofibromin gene is highly expressed in the developing brain of the embryo. In the adult brain, expression can be found in the Purkinje cells, pyramidal cells, Schwann cells and oligodendrocytes. The RAS/MAPK signalling pathway plays a critical role in memory formation and learning through long lasting alterations of gene expression in neuronal cells. Therefore, learning deficits could be explained by alterations in this important signalling pathway, however, learning disabilities in patients with Neurofibromatosis are variable (Costa et al., 2001; Costa et al., 2002). Neurofibromin knock-out mice have confirmed learning deficits in mice due to RAS hyperactivity. Treatment with a farnesyl-transferase inhibitor could reverse some of the effects of the mutation in mice (Costa et al., 2002).

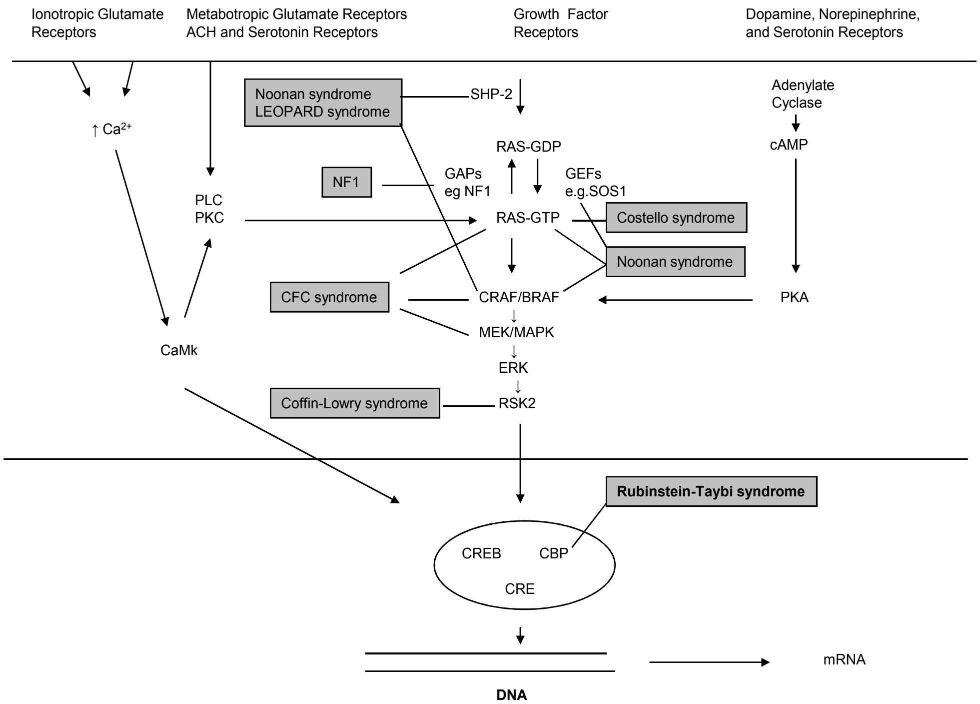

Fig. 1. The Neuro-Cardio-Facio-Cutaneous syndrome family and its relationship to mutations in proteins of the RAS/MAPK signalling cascade. Solid lines indicate associations to mutations in the proteins involved in the signalling cascade. Arrows indicate activating and inactivating events. Abbreviations: Ca^{2+}, ionic calcium; ACH, Acetylcholine; CaMk, Calcium-calmodulin kinase; PLC, Phospholipase C; PKC, Phosphokinase C; SHP-2, Src homology 2 domain-containing-transforming protein; NF1, neurofibromatosis type 1; GDP, guanine dinucleotide phosphate; GEF, guanine-nucleotide-exchange factor; SOS1, son of sevenless homologue 1; GTP, guanine trinucleotide phosphate; GAP, GTPase-stimulating proteins; cAMP, cyclic adenosine monophosphate; PKA, Protein kinase A; CRAF, RAF1 v-raf-1 murine leukemia viral oncogene homolog 1; BRAF, *v-raf* murine sarcome viral oncogene homologue B1; MEK, mitogen-activated protein kinase kinase; MAPK, mitogen-activated protein kinase; ERK, Extracellular signal-regulated kinase; RSK2, ribosomal S6-kinase 2; CREB, CRE binding protein; CBP, CREB binding protein; CRE, cAMP response-element; CFC, cardio-facio-cutaneous.

3.7 Coffin-Lowry syndrome

Coffin-Lowry syndrome (MIM 303600) is a severe mental retardation syndrome with mutations in the ERK/CREB pathway, which is activated by the RAS/MAPK signalling cascade (Figure 1). This rare mental retardation disorder is characterized by an abnormal gait, facial abnormalities including protruding forehead, wide nose, and irregular teeth. Individuals affected with this syndrome are often short with poor bone mineralization and underdevelopment of the musculature (Coffin et al., 1966; Lowry et al., 1971). Coffin-Lowry syndrome is caused by a wide variety of mutations in the gene 90 kDa ribosomal S6 serin-threonine kinase 2 (*RSK2)* located on chromosome Xp22.2 (Trivier et al., 1996). The spectrum of mutations includes splice site alterations, missense mutations, frame-shift alterations, and nonsense mutations. In the hippocampus, RSK2 phosphorylates and activates a number of nuclear proteins including CREB when activated by the ERK pathway (Jacquot et al., 1998; Xing et al., 1996). The RSK2 mutant mouse model resembles the Coffin-Lowry syndrome patients in that it shows marked deficits in motor development, coordination and spatial learning (Dufresne et al., 2001).

Syndrome	Gene	Chromosome	References
Noonan syndrome	*PTPN11*	12q24.13	Tartaglia et al., 2001
	SOS1	2p22-p21	Roberts et al., 2007 Tartaglia et al., 2007
	RAF1	3p25	Pandit et al., 2007; Razzaque et al., 2007
	KRAS	12p12.1	Schubbert et al., 2006; Zenker et al., 2007
LEOPARD syndrome	*PTPN11*	12q24.13	Digilio et al., 2002; Legius et al., 2002
	RAF1	3p25	Pandit et al., 2007
Costello syndrome	*HRAS*	11p15.5	Aoki et al., 2005
Cardio-facio-cutaneous syndrome	*BRAF*	7q34	Rauen, 2006; Schulz et al., 2008; Narumi et al., 2007; Nava et al., 2007; Gripp et al., 2007
	MAP2K1	15q22.31	Rodriguez-Viciana et al., 2006
	MAP2K2	19p13.3	Rodriguez-Viciana et al., 2006
	KRAS	12p12.1	Schubbert et al. 2006; Niihori et al., 2006
Neurofibromatosis	*NF1*	17q11.2	Viskochil et al., 1990
Coffin-Lowry syndrome	*RSK2*	Xp22.2	Trivier et al., 1996
Rubinstein-Taybi syndrome	*CBP*	16p13.3	Petrij et al., 1995

Table 1. Genetic syndromes linked to genes in the RAS/MAPK pathway

3.8 Rubinstein-Taybi syndrome

A patho-mechanistically related disorder is the Rubinstein-Taybi syndrome (MIM 180849), a rare mental retardation syndrome occurring with a frequency of 1 in 125,000 live births. This autosomal dominant syndrome is characterized by distinct facial features, broad digits, angulated thumb, and blunted growth (Rubinstein & Taybi, 1963; Rubinstein, 1990). A variety of mutations in the gene transcriptional co-activator CREB-binding protein (*CREB)* have been identified in about 50% of patients (Petrij et al., 1995; Blough et al., 2000). *CREB* is located on chromosome 16p13.3. Mutations in this gene lead to protein changes that interfere with the binding of the transcription factor CRE through alterations in the chromatin structure within the promoter regions of the CRE regulated genes (Ogryzko et al., 1996). A mouse model carrying a dominant negative mutation in *CREB* displayed nearly all the features of Rubinstein-Taybi syndrome including deficits in long-term memory (Oike et al., 1999). The short-term memory was unimpaired.

From this short overview of the neuro-cardio-facio-cutaneous syndromes is becomes clear that despite the common effect of increased signal transmission through the RAS/MAPK pathway, known mutations in component of this pathway lead to highly variable but distinct effect on the phenotype (Cesarini et al., 2009; Niihori et al., 2006; Rodriguez-Viciana et al., 2006; Garnett et al., 2005). The degree of cognitive impairment varies among syndromes, ranging from normal cognition in some cases of NF1 and Noonan syndrome to severe impairment in some cases of CFC-syndrome (Denayer et al., 2008). Overall, it can be said that mutations upstream of RAS seem to have less severe and more variable effects on cognitive impairment, whereas mutations in genes closer to the nucleus appear to have more detrimental effects. The success in identifying the underlying genetic mutations in these rare developmental Mendelian disorders was based on the presence of overlapping clinical phenotypes that pointed to possible candidate pathways. Common symptoms in many body systems allowed for the identification of groups of patients that were similar in their underlying pathophysiology and their genetic risk factors. Nevertheless, even in these homogeneous patient populations the genetic causes of the disorders were highly variable often involving several genes in the same pathway. Despite the success described above, the known mutations still explain only a portion of all the cases diagnosed with a particular syndrome on clinical grounds.

X-linked mental retardation is another example of a condition that is characterized by extensive heterogeneity. Only a percentage of cases can be explained by known genetic mutations. The absence of additional clinical features prohibits the sub-classification of patients into more homogeneous groups based on clinical presentation. The underlying heterogeneity of the genetic causes hinders the utilization of family-based linkage analyses and population-based association studies. Therefore, this disease category required a substantially different approach to the identification of the underlying genetic causes.

4. X-lined mental retardation

The frequency of mild to moderate mental disability defined as an IQ between 50 and 70 is about 2-3% in the general population; more severe intellectual impairment is found in 0.5 to 1% of the population (Raymond, 2006). A significant portion of these disorders is inherited in an X-linked mode. About 80 genes located on the X-chromosome are known to be involved in mental retardation to date and many more are likely to be discovered. Many families have rare or even private disease-causing mutations that are not shared with other families and in a large percentage of these families mental retardation is the only symptom present. Direct re-sequencing approaches appear to be the only way to identify the underlying mutations in these families.

A recent study involving patients affected with X-linked mental retardation used a large-scale systematic re-sequencing approach to explore genomic variants present in the patients compared to their unaffected relatives. The study involved 208 families and focussed on the coding exons of all the genes located on the X-chromosome in a systematic approach (Tarpey et al., 2009). First, protein truncating changes in the coding regions of genes were analyzed since these changes could be expected to have the most severe consequences for the function of the protein. Using this approach mutations in four new genes were detected that were not previously known to be involved in mental retardation. A large number of truncating mutations were identified. Overall, the majority of truncating mutations were not associated with disease status at all and even loss of about 1% of genomic material on the x-chromosome was compatible with a normal phenotype. Truncating mutations associated with the phenotype were found in 10% of the genes located on the X-chromosome. However, each particular genomic change explained only a very small portion of mental retardation in the sample and in the majority of families the underlying genetic mutation could not be identified.

In addition to truncating mutations, a large number of single nucleotide polymorphisms were found. Almost 2,000 single-nucleotide genomic variants were detected in the coding sequences of the genes alone. Almost half of these mutations were missense mutations leading to amino acid substitutions in the encoded proteins. Rare small insertions and deletions were also present. Nearly half of the mutations were found only once in the sample. Slightly more than half of the recurrent variants could be found in public databases for common genomic polymorphisms. On average, the genomic sequence of any two individuals differed by about 100 variants in the coding regions alone. These results demonstrate the large amount of genomic variability that is present between any two individual genomes. Evaluation of the functional consequences of those genomic variants would be a daunting task. In addition it is likely that many variants with physiological consequences have been missed since introns of genes, the promoter regions or other non-coding regions have not even been sequenced in this study. These genomic regions are known to have important regulatory functions for gene expression and are even more variable than the coding regions themselves.

In summary, it could be said that substantial genetic heterogeneity was found underlying X-linked mental retardation. At least 10% of the genes located on the X-chromosome were involved, individual mutations were generally rare and each identified gene accounted only for a small portion of the cases. In addition to disease-causing mutations, a large number of rare non-synonymous mutations were identified that had no apparent effect on the phenotype. A surprising result of this study was that a large number of mutations interrupting the function of the gene were not causally related to mental retardation at all. In fact, loss of about 1% of genetic material on the X-chromosome was compatible with a normal phenotype. In this context it is important to stress that the identification of a rare truncating mutation in studies with large sample size will still require careful follow-up evaluation of the functional consequences and should not be considered as evidence for disease causation per se (Raymond et al., 2009). Despite its success, this study paints a daunting picture of the task ahead in the search for genomic variants underlying common complex disorders. Nevertheless, even the identification of rare mutations in a small number of cases might shed some light on underlying pathomechanisms of the disease.

Schizophrenia is another disorder that is heavily researched, because improvement in the understanding of the underlying pathophysiology of this disorder promises to provide new treatment options. Schizophrenia shares many features with developmental disorders, as well as mental retardation syndromes including strong evidence for a genetic cause of the disease. Until now much uncertainty still exists regarding specific genetic variants that might contribute to the phenotype.

5. Schizophrenia

Schizophrenia is a common psychiatric disorder affecting about 0.5%-1% of the population. The clinical phenotype is characterized by dissociation of thoughts and emotions, distorted perception of reality manifested as hallucinations and delusions, as well as emotional flattening over the disease course. The age of onset is usually in adolescence. Schizophrenia is often conceptualized as a complex disorder caused by multiple common genomic variants with small effect size in combination with environmental risk factors (Williams et al., 2009). Significant familiality and heritability have been demonstrated for this disorder (Cardno & Gottesman, 2000). Despite the fact that genetic risk factors play an important role in the manifestation of the disease, it has been difficult to replicate genome-wide significant linkage signals consistently (Williams et al., 2009). Even genome-wide association studies in thousands of individuals still left some doubt about underlying genetic risk factors (Allen et al, 2008; Need et al., 2009). The increase in power that was hoped for by collecting ever larger sample sizes might have been counteracted by increased heterogeneity of the disease (Craddock et al., 2008). If the same degree of heterogeneity is present in schizophrenia as it was found in developmental disorders or X-linked mental retardation, these results would not be surprising.

Schizophrenia is often conceptualized as a developmental disorder. Candidate gene studies based on various hypotheses of disease pathology have been numerous with inconsistent results (Allen et al., 2008). In particular, these studies have been hindered by the fact that the symptoms of schizophrenia are rather non-specific and manifestations in other body systems are often lacking. Due to possible heterogeneity, replication of candidate gene association studies has been difficult and results have often not been convincing. Positional candidate gene studies that follow-up on significant family-based linkage studies have been more successful revealing several potential risk genes including neuregulin 1 (*NRG1)*, dystrobrevin-binding protein 1 *(DTNBP1*), and D-amino acid oxidase inhibitor *(DAOA)*, among others (Williams et al. 2009). However, overall mutations in these genes could explain only a very small percentage of cases.

Recently, the focus of research has shifted from common single nucleotide polymorphisms to rare structural variants. This shift might have been inspired by the finding that about 10% of neuro-developmental disorders including autism and mental retardation are caused by non-inherited deletions and insertions of genetic material (Sebat et al, 2007; Autism Genome Project Consortium, 2007). Recent genome-wide studies in schizophrenia reported large multigenic deletions located on chromosomes 1q21.1 and 15q13.3, which were present in a very small number of individuals diagnosed with schizophrenia (International Schizophrenia Consortium, 2008; Stefansson et al., 2008; Need et al., 2009; Kirov G, 2009). In addition, exon-disrupting copy number variations have been identified in the gene NRXN1 (Rujescu et al., 2009). Several of the deletions associated with schizophrenia had previously been associated with mental retardation, autism, ADHD, and other neuro-developmental disorders, including seizures (Mefford et al., 2008; Wassink et al., 2001; Sharp et al., 2008). Subsequent studies have confirmed these associations in a number of individuals (van Bon et al, 2009; Helbig et al., 2009; Miller et al., 2009; Ben-Shachar et al., 2009). It is long known that autism and other mental disorders share common symptoms with schizophrenia. The presence of a small number of individuals affected with these mental disorders in a large sample of thousands of cases affected with schizophrenia could lead to statistically significant results. Especially in large samples diagnostic uncertainty cannot always be completely excluded, and therefore, careful follow-up with functional studies on the results in schizophrenia would be prudent. Overall, research in schizophrenia points to the possibility of heterogeneity similar to results in rare Mendelian developmental disorders and complex X-linked mental retardation.

6. Discussion

Finding genetic risk factors in common complex mental disorders is an area of intense research. Linkage studies, positional candidate gene sequencing approaches, as well as the search for truncating mutations that severely disrupt the function of a protein are traditional tools that have been applied successfully to rare Mendelian genetic syndromes leading to the identification of rare Mendelian variants. In common complex mental disorders, on the other hand, it has been the accepted hypothesis that different genetic risk factors might play a role. Common complex disorders are thought to involve common genomic variants present in at least one percent of the population. Genome-wide association studies have been designed to find few common risk variants that would explain the pathophysiology of common complex disorders. Even though these studies have been successful in identifying common variants with low associated risk in some disorders, it has to be admitted that the majority of cases still remains unexplained. This scenario leaves several open questions. Could it be that common complex disorders after all are not so different from rare Mendelian disorders? Could it be that the effect of the mutations involved is only less pronounced and easier to compensate? Could it be that common complex disorders are as heterogeneous as Mendelian disorders, as demonstrated in X-linked mental retardation? In this disorder close to hundred different genetic causes have been identified, each of which is individually rare. Nevertheless, the majority of cases still remains unexplained. Could psychiatric disorders such as bipolar disorder and schizophrenia be more heterogeneous with regard to their underlying pathophysiology and genetic risk factors than we ever would have imagined? Could it be that these disorders are caused by many rare genetic mutations, some of which would be present in only a small number of families? The answer to these questions can only come from further research. However, even considering these scenarios would require different strategic approaches. It might be useful to reconsider proven technologies, such as positional candidate gene sequencing and family based studies in addition to large-scale genome-wide approaches. It could be useful to consider the possibility that collecting an ever-larger number of samples might only increase the heterogeneity of the cases. In the end it might be useful to refocus on the evaluation of functional consequences of mutations instead of being mesmerized by bio-statistical p-values. The answer to these questions must remain unknown. The comparison of different research strategies in related fields might be instructive and inspiring. After all, mental retardation is about as frequent as psychotic disorders in the general population and developmental syndromes might actually be among samples of schizophrenia patients, since they often share symptoms of hallucinations and delusions. In the end, considering all possible approaches might be the way that will enhance our understanding of mental disorders.

7. Conclusion

As the focus in common complex mental disorders has shifted from hypothesis-based candidate gene approaches to genome-wide explorations, the focus might shift from common genomic variants to the detection of rare variants. Research strategies might adjust as well moving from genome-wide association studies of common variants to re-sequencing approaches of entire genomes. While this shift takes place it could be instructive to study some of the lessons learned from hypothesis driven re-sequencing approaches in developmental disorders and chromosome-wide re-sequencing studies in X-linked mental retardation. Re-sequencing approaches have been successful in identifying new genes of unknown function, for which prior hypothesis did not exist before. On the other hand, follow-up and evaluation of the large amount of common and rare variants identified by this approach could be challenging. As genome-wide re-sequencing studies will most likely reveal a tremendous amount of genomic variants, hypothesis driven approaches might be very useful in follow-up of genome-wide sequencing approaches, particularly in a world of limited resources of time and money. Family-based re-sequencing approaches as compared to population-based approaches will allow detecting the segregation of the phenotype with the genotype. This might be a useful prerequisite for separating random noise of genomic variability from disease causing variants. Functional tests will in the end be required to ultimately inform about disease patho-physiology. Last but not least, rare and private mutations might be more commonly involved in disease pathology than we would have ever imagined.

8. References

Allen, N.C.; Bagade, S.; McQueen, M.B.; Ioannidis, J.P.; Kavvoura, F.K.; Khoury, M.J.; Tanzi, R.E. & Bertram, L. (2008). Systematic meta-analyses and field synopsis of genetic association studies in schizophrenia, the SzGene database. *Nat. Genet.*, Vol. 40, 827–834

Aoki, Y.; Niihori, T.; Kawame, H.; Kurosawa, K.; Ohashi, H.; Tanaka, Y.; Filocamo, M.; Kato, K.; Suzuki, Y.; Kure, S. & Matsubara, Y. (2005). Germline mutations in HRAS proto-oncogene cause Costello syndrome. *Nat. Genet.*, Vol. 37, No. 10, 1038-1040

Aoki, Y.; Niihori, T.; Narumi, Y.; Kure, S. & Matsubara, Y. (2008). The RAS/MAPK syndromes: novel roles of the RAS pathway in human genetic disorders. *Hum. Mutat.*, Vol. 29, No. 8, 992-1006

Autism Genome Project Consortium. (2007). Mapping autism risk loci using genetic linkage and chromosomal rearrangements. *Nat. Genet.*, Vol. 39, 319–328

Axelrad, M.E.; Nicholson, L.; Stabley, D.L.; Sol-Church, K. & Gripp, K.W. (2007). Longitudinal assessment of cognitive characteristics in Costello syndrome. *Am. J. Med. Genet. A.*, Vol. 143A, No. 24, 3185-3193

Ben-Shachar, S.; Lanpher, B.; German, J.R.; Qasaymeh, M.; Potocki, L.; Nagamani, S.C.; Franco, L.M.; Malphrus, A.; Bottenfield, G.W.; Spence, J.E.; Amato, S.; Rousseau, J.A.; Moghaddam, B.; Skinner, C.; Skinner, S.A.; Bernes, S.; Armstrong, N.; Shinawi, M.; Stankiewicz, P.; Patel, A.; Cheung, S.W.; Lupski, J.R.; Beaudet, A.L. & Sahoo, T. (2009). Microdeletion 15q13.3: a locus with incomplete penetrance for autism, mental retardation, and psychiatric disorders. *J. Med. Genet.*, Vol. 46, No. 6, 382-388

Blough, R.I.; Petrij, F.; Dauwerse, J.G.; Milatovich-Cherry, A.; Weiss, L.; Saal, H.M. & Rubinstein, J.H. (2000). Variation in microdeletions of the cyclic AMP-responsive element-binding protein gene at chromosome band 16p13.3 in the Rubinstein-Taybi syndrome. *Am. J. Med. Genet.*, Vol. 90, No. 1, 29-34

Borradori, L. & Blanchet-Bardon, C. (1993). Skin manifestations of cardio-facio-cutaneous syndrome. *J. Am. Acad. Dermatol.*, Vol. 28, No. 5 Pt 2, 815-819

Cardno, A.G. & Gottesman, I.I. (2000). Twin studies of schizophrenia: from bow-and-arrow concordances to star wars Mx and functional genomics. *Am. J. Med. Genet.*, Vol. 97, 12–17

Cesarini, L.; Alfieri, P.; Pantaleoni, F.; Vasta, I.; Cerutti, M.; Petrangeli, V.; Mariotti, P.; Leoni, C.; Ricci, D.; Vicari, S.; Selicorni, A.; Tartaglia, M.; Mercuri, E. & Zampino, G. (2009). Cognitive profile of disorders associated with dysregulation of the RAS/MAPK signaling cascade. *Am. J. Med. Genet*. A., Vol. 149A, No. 2, 140-146

Chan, P.C.; Chiu, H.C. & Hwu, W.L. (2002). Spontaneous chylothorax in a case of cardio-facio-cutaneous syndrome. *Clin. Dysmorphol*., Vol. 11, No. 4, 297-298

Coffin, G.S.; Siris, E. & Wegienka, L.C. (1966). Mental retardation with osteocartilaginous anomalies. *Am. J. Dis. Child*, 205-213

Costa, R.M.; Yang, T.; Huynh, D.P.; Pulst, S.M.; Viskochil, D.H.; Silva, A.J. & Brannan, C.I. (2001). Learning deficits, but normal development and tumor predisposition, in mice lacking exon 23a of Nf1. *Nat. Genet*., Vol. 27, No. 4, 399-405

Costa, R.M.; Federov, N.B.; Kogan, J.H.; Murphy, G.G.; Stern, J.; Ohno, M.; Kucherlapati, R.; Jacks, T. & Silva, A.J. (2002). Mechanism for the learning deficits in a mouse model of neurofibromatosis type 1. *Nature*, Vol. 415, No. 6871, 526-530

Costello, J.M. (1971). A new syndrome. *NZ Med. J*., Vol. 74, 397

Costello, J.M. (1977). A new syndrome: mental subnormality and nasal papillomata. *Aust. Paediatr. J*., Vol. 13, No. 2, 114-118

Craddock, N.; O'Donovan, M.C. & Owen, M.J. (2008). Genome-wide association studies in psychiatry: lessons from early studies of non-psychiatric and psychiatric phenotypes. *Mol. Psychiatry*, Vol. 13, 649–653

Delrue, M.A.; Chateil, J.F.; Arveiler, B. & Lacombe, D. (2003). Costello syndrome and neurological abnormalities. *Am. J. Med. Genet*. A., Vol. 123A, No. 3, 301-305

Denayer, E.; de Ravel, T.; Legius, E. (2008). Clinical and molecular aspects of RAS related disorders. *J. Med. Genet*., Vol. 45, No. 11, 695-703.

Digilio, M.C.; Conti, E.; Sarkozy, A.; Mingarelli, R.; Dottorini, T.; Marino, B.; Pizzuti, A. & Dallapiccola, B. (2002). Grouping of multiple-lentigines/LEOPARD and Noonan syndromes on the PTPN11 gene. *Am. J. Hum. Genet*., Vol. 71, 389-394

Dufresne, S.D.; Bjørbaek, C.; El-Haschimi, K.; Zhao, Y.; Aschenbach, W.G.; Moller, D.E. & Goodyear L.J. (2001). Altered extracellular signal-regulated kinase signaling and glycogen metabolism in skeletal muscle from p90 ribosomal S6 kinase 2 knockout mice. *Mol. Cell Biol*., Vol. 21, No. 1, 81-87

Garnett, M.J.; Rana, S.; Paterson, H.; Barford, D. & Marais, R. (2005). Wild-type and mutant B-RAF activate C-RAF through distinct mechanisms involving heterodimerization. *Mol. Cell*., Vol. 20, No. 6, 963-969

Gibbs, J.B.; Sigal, I.S.; Poe, M. & Scolnick, E.M. (1984). Intrinsic GTPase activity distinguishes normal and oncogenic ras p21 molecules. *Proc. Natl. Acad. Sci. U.S.A*., Vol. 81, No. 18, 5704-5708

Grebe, T.A. & Clericuzio, C. (2000). Neurologic and gastrointestinal dysfunction in cardio-facio-cutaneous syndrome: identification of a severe phenotype. *Am. J. Med. Genet*., Vol. 95, No. 2, 135-143

Gripp, K.W.; Lin, A.E.; Stabley, D.L.; Nicholson, L.; Scott, C.I. Jr.; Doyle, D.; Aoki, Y.; Matsubara, Y.; Zackai, E.H.; Lapunzina, P.; Gonzalez-Meneses, A.; Holbrook, J.; Agresta, C.A.; Gonzalez, I.L. & Sol-Church, K. (2006). HRAS mutation analysis in Costello syndrome: genotype and phenotype correlation. *Am. J. Med. Genet. A.*, Vol. 140, No. 1, 1-7

Gripp, K.W.; Lin, A.E.; Nicholson, L.; Allen, W.; Cramer, A.; Jones, K.L.; Kutz, W.; Peck, D.; Rebolledo, M.A.; Wheeler, P.G.; Wilson, W.; Al-Rahawan, M.M.; Stabley, D.L. & Sol-Church, K. (2007). Further delineation of the phenotype resulting from BRAF or MEK1 germline mutations helps differentiate cardio-facio-cutaneous syndrome from Costello syndrome. *Am. J. Med. Genet.* A, Vol. 143A, No. 13, 1472-1480

Hancock, J.F. (2003). Ras proteins: different signals from different locations. *Nat. Rev. Mol. Cell Biol.,* Vol. 4, No. 5, 373-384

Helbig, I.; Mefford, H.C.; Sharp, A.J.; Guipponi, M.; Fichera, M.; Franke, A.; Muhle, H.; de Kovel, C.; Baker, C.; von Spiczak, S.; Kron, K.L.; Steinich, I.; Kleefuss-Lie, A.A.; Leu, C.; Gaus, V.; Schmitz, B.; Klein, K.M.; Reif, P.S.; Rosenow, F.; Weber, Y.; Lerche, H.; Zimprich, F.; Urak, L.; Fuchs, K.; Feucht, M.; Genton, P.; Thomas, P.; Visscher, F.; de Haan, G.J.; Møller, R.S.; Hjalgrim, H.; Luciano, D.; Wittig, M.; Nothnagel, M.; Elger, C.E.; Nürnberg, P.; Romano, C.; Malafosse, A.; Koeleman, B.P.; Lindhout, D.; Stephani, U.; Schreiber, S.; Eichler, E.E. & Sander, T. (2009). 15q13.3 microdeletions increase risk of idiopathic generalized epilepsy. *Nat. Genet.,* Vol. 41, No. 2, 160-162

Hennekam, R.C. (2003). Costello syndrome: an overview. *Am. J. Med. Genet. C Semin. Med. Genet*., Vol. 117C, No. 1, 42-48

Herman, T.E. & McAlister, W.H. (2005). Gastrointestinal and renal abnormalities in cardio-facio-cutaneous syndrome. *Pediatr. Radiol*., Vol. 35, No. 2, 202-205

International Schizophrenia Consortium. (2008). Rare chromosomal deletions and duplications increase risk of schizophrenia. *Nature*, Vol. 455, 237–241

Jacquot, S.; Merienne, K.; De Cesare, D.; Pannetier, S.; Mandel, J.L.; Sassone-Corsi, P. & Hanauer, A. (1998). Mutation analysis of the RSK2 gene in Coffin-Lowry patients: extensive allelic heterogeneity and a high rate of de novo mutations. *Am. J. Hum. Genet.*, Vol. 63, No. 6,1631-1640

Kerr, B.; Delrue, M.A.; Sigaudy, S.; Perveen, R.; Marche, M.; Burgelin, I.; Stef, M.; Tang, B.; Eden, O.B.; O'Sullivan, J.; De Sandre-Giovannoli, A.; Reardon, W.; Brewer, C.; Bennett, C.; Quarell, O.; M'Cann, E.; Donnai, D.; Stewart, F.; Hennekam, R.; Cavé, H.; Verloes, A.; Philip, N.; Lacombe, D.; Levy, N.; Arveiler, B. & Black, G. (2006). Genotype-phenotype correlation in Costello syndrome: HRAS mutation analysis in 43 cases. J. *Med. Genet*., Vol. 43, No. 5, 401-405

Kirov, G.; Grozeva, D.; Norton, N.; Ivanov, D.; Mantripragada, K.K.; Holmans, P.; International Schizophrenia Consortium; Wellcome Trust Case Control Consortium; Craddock, N.; Owen, M.J. & O'Donovan, M.C. (2009) Support for the involvement of large CNVS in the pathogenesis of schizophrenia. *Hum. Mol. Genet*, Vol. 18, 1497–1503

Lee, D.A.; Portnoy, S.; Hill, P.; Gillberg, C. & Patton, M.A. (2005). Psychological profile of children with Noonan syndrome. *Dev. Med. Child. Neurol*., Vol. 47, No. 1, 35-38

Legius, E.; Schrander-Stumpel, C.; Schollen, E.; Pulles-Heintzberger, C.; Gewillig, M.; Fryns, J.P. (2002). PTPN11 mutations in LEOPARD syndrome. *J. Med. Genet*., Vol. 39, 571-574

Lowry, B.; Miller, J.R. & Fraser, F.C. (1971). A new dominant gene mental retardation syndrome. Association with small stature, tapering fingers, characteristic facies, and possible hydrocephalus. *Am. J. Dis. Child*, Vol. 121, No. 6, 496-500

McGrath, J.P.; Capon, D.J.; Goeddel, D.V. & Levinson, A.D. (1984). Comparative biochemical properties of normal and activated human ras p21 protein. *Nature*, Vol. 310, No. 5979, 644-649

Mefford, H.C.; Sharp, A.J.; Baker, C.; Itsara, A.; Jiang, Z.; Buysse, K.; Huang, S.; Maloney, V.K.; Crolla, J.A.; Baralle, D.; Collins, A.; Mercer, C.; Norga, K.; de Ravel, T.; Devriendt, K.; Bongers, E.M.; de Leeuw, N.; Reardon, W.; Gimelli, S.; Bena, F.; Hennekam, R.C.; Male, A.; Gaunt, L.; Clayton-Smith, J.; Simonic, I.; Park, S.M.; Mehta, S.G.; Nik-Zainal, S.; Woods, C.G.; Firth, H.V.; Parkin, G.; Fichera, M.; Reitano, S.; Lo Giudice, M.; Li, K.E.; Casuga, I.; Broomer, A.; Conrad, B.; Schwerzmann, M.; Räber, L.; Gallati, S.; Striano, P.; Coppola, A.; Tolmie, J.L.; Tobias, E.S.; Lilley, C.; Armengol, L.; Spysschaert, Y.; Verloo, P.; De Coene, A.; Goossens, L.; Mortier, G.; Speleman, F.; van Binsbergen, E.; Nelen, M.R.; Hochstenbach, R.; Poot, M.; Gallagher, L.; Gill, M.; McClellan, J.; King, M.C.; Regan. R.; Skinner, C.; Stevenson, R.E.; Antonarakis, S.E.; Chen, C.; Estivill, X.; Menten, B.; Gimelli, G.; Gribble, S.; Schwartz, S.; Sutcliffe, J.S.; Walsh, T.; Knight, S.J.; Sebat, J.; Romano, C.; Schwartz, C.E.; Veltman, J.A.; de Vries, B.B.; Vermeesch, J.R.; Barber, J.C.; Willatt, L.; Tassabehji, M. & Eichler, E.E. (2008). Recurrent rearrangements of chromosome 1q21.1 and variable pediatric phenotypes. *N. Engl. J. Med.*, Vol. 359, No. 16, 1685-1699

Miller, D.T.; Shen, Y.; Weiss, L.A.; Korn, J.; Anselm, I.; Bridgemohan, C.; Cox, G.F.; Dickinson, H.; Gentile, J.; Harris, D.J.; Hegde, V.; Hundley, R.; Khwaja, O.; Kothare, S.; Luedke, C.; Nasir, R.; Poduri, A.; Prasad, K.; Raffalli, P.; Reinhard, A.; Smith, S.E.; Sobeih, M.M.; Soul, J.S.; Stoler, J.; Takeoka, M.; Tan, W.H.; Thakuria, J.; Wolff, R.; Yusupov, R.; Gusella, J.F.; Daly, M.J.; Wu, B.L. (2009). Microdeletion/duplication at 15q13.2q13.3 among individuals with features of autism and other neuropsychiatric disorders. *J. Med. Genet.*, Vol. 46, No. 4, 242-248

Narumi, Y.; Aoki, Y.; Niihori, T.; Niihori, T.; Neri, G.; Cavé, H.; Verloes, A.; Nava, C.; Kavamura, M.I.; Okamoto, N.; Kurosawa, K.; Hennekam, R.C.; Wilson, L.C.; Gillessen-Kaesbach, G.; Wieczorek, D.; Lapunzina, P.; Ohashi, H.; Makita, Y.; Kondo, I..; Tsuchiya, S.; Ito, E.; Sameshima, K.; Kato, K.; Kure, S. & Matsubara, Y.; (2007). Molecular and clinical characterization of cardio-facio-cutaneous (CFC) syndrome: Overlapping clinical manifestations with Costello syndrome. *Am. J. Med. Genet.* Part A, Vol 143A, 799–807.

Nava, C.; Hanna, N.; Michot, C.; Pereira, S.; Pouvreau, N.; Niihori, T.; Aoki, Y.; Matsubara, Y.; Arveiler, B.; Lacombe, D.; Pasmant, E.; Parfait, B.; Baumann, C.; Héron, D.; Sigaudy, S.; Toutain, A.; Rio, M.; Goldenberg, A.; Leheup, B.; Verloes, A. & Cavé, H. (2007). Cardio-facio-cutaneous and Noonan syndromes due to mutations in the RAS/MAPK signalling pathway: genotype-phenotype relationships and overlap with Costello syndrome. *J. Med. Genet.*, Vol. 44, No. 12, 763-771

Need, A.C.; Ge, D.; Weale, M.E.; Maia, J.; Feng, S.; Heinzen, E.L.; Shianna, K.V.; Yoon, W.; Kasperaviciūte, D.; Gennarelli, M.; Strittmatter, W.J.; Bonvicini, C.; Rossi, G.; Jayathilake, K.; Cola, P.A.; McEvoy, J.P.; Keefe, R.S.; Fisher, E.M.; St Jean, P.L.; Giegling, I.; Hartmann, A.M.; Möller, H.J.; Ruppert, A.; Fraser, G.; Crombie, C.; Middleton, L.T.; St Clair, D.; Roses, A.D.; Muglia, P.; Francks, C.; Rujescu, D.; Meltzer, H.Y. & Goldstein, D.B. (2009). A genome-wide investigation of SNPs and CNVs in schizophrenia. *PLoS Genet.* , Vol. 5, No. 2, e1000373. Erratum in: *PLoS*

Genet. Vol. 5, No. 3 doi: 10.1371/annotation/e0196ebb-de40-453f-8f8c-791b126618da.

Niihori, T.; Aoki, Y.; Narumi, Y.; Neri, G.; Cavé, H.; Verloes, A.; Okamoto, N.; Hennekam, R.C.; Gillessen-Kaesbach, G.; Wieczorek, D.; Kavamura, M.I.; Kurosawa, K.; Ohashi, H.; Wilson, L.; Heron, D.; Bonneau, D.; Corona, G.; Kaname, T.; Naritomi, K.; Baumann, C.; Matsumoto, N.; Kato, K.; Kure, S. & Matsubara, Y. (2006). Germline KRAS and BRAF mutations in cardio-facio-cutaneous syndrome. *Nat. Genet.*, Vol. 38, No. 3, 294-296

Noonan, J.A. (1968). Hypertelorism with Turner phenotype. A new syndrome with associated congenital heart disease. *Am. J. Dis. Child*., Vol. 116, No. 4, 373-380

O'Connell, P.; Cawthon, R.; Xu, G.F.; Li, Y.; Viskochil, D. & White, R. (1992). The neurofibromatosis type 1 (NF1) gene: identification and partial characterization of a putative tumor suppressor gene. *J. Dermatol.*, Vol. 19, No. 11, 881-884

Ogryzko, V.V.; Schiltz, R.L.; Russanova, V.; Howard, B.H. & Nakatani, Y. (1996). The transcriptional coactivators p300 and CBP are histone acetyltransferases. *Cell*, Vol. 87, No. 5, 953-959

Oike, Y.; Hata, A.; Mamiya, T.; Kaname, T.; Noda, Y.; Suzuki, M.; Yasue, H.; Nabeshima, T.; Araki, K.; Yamamura, K. (1999). Truncated CBP protein leads to classical Rubinstein-Taybi syndrome phenotypes in mice: implications for a dominant-negative mechanism. *Hum. Mol. Genet*., Vol. 8, No. 3, 387-396

Pandit, B.; Sarkozy, A.; Pennacchio, L.A.; Carta, C.; Oishi, K.; Martinelli, S; Pogna, E.A.; Schackwitz, W.; Ustaszewska, A.; Landstrom, A.; Bos, J.M.; Ommen, S.R.; Esposito, G.; Lepri, F.; Faul, C.; Mundel, P.; López Siguero, J.P.; Tenconi, R.; Selicorni, A.; Rossi, C.; Mazzanti, L.; Torrente, I.; Marino, B.; Digilio, M.C.; Zampino, G.; Ackerman, M.J.; Dallapiccola, B.; Tartaglia, M. & Gelb, B.D. (2007). Gain-of-function RAF1 mutations cause Noonan and LEOPARD syndromes with hypertrophic cardiomyopathy. *Nat. Genet*., Vol. 39, No. 8, 1007-1012

Petrij, F.; Giles, R.H.; Dauwerse, H.G.; Saris, J.J.; Hennekam, R.C.; Masuno, M.; Tommerup, N.; van Ommen, G.J.; Goodman, R.H.; Peters, D.J. & Breuning, M.H. (1995). Rubinstein-Taybi syndrome caused by mutations in the transcriptional co-activator CBP. *Nature,* Vol. 376, No. 6538, 348-351

Pierpont, E.I.; Pierpont, M.E.; Mendelsohn, N.J.; Roberts, A.E.; Tworog-Dube, E. & Seidenberg M.S. (2009). Genotype differences in cognitive functioning in Noonan syndrome. *Genes Brain Behav*., Vol. 8, No. 3, 275-282

Rauen, K.A. (2006). Distinguishing Costello versus cardio-facio-cutaneous syndrome: BRAF mutations in patients with a Costello phenotype. *Am. J. Med. Genet*. A., Vol. 140, No. 15, 1681-1683

Raymond, F.L. (2006). X linked mental retardation: a clinical guide. *J. Med. Genet*., Vol. 43, No. 3, 193-200

Raymond, F.L.; Whibley, A.; Stratton, M.R. & Gecz, J. (2009). Lessons learnt from large-scale exon re-sequencing of the X chromosome. *Hum. Mol. Genet*., Vol. 18, No. R1, R60-64

Razzaque, M.A.; Nishizawa, T.; Komoike, Y.; Yagi, H.; Furutani, M.; Amo, R.; Kamisago, M.; Momma, K.; Katayama, H.; Nakagawa, M.; Fujiwara, Y.; Matsushima, M.; Mizuno, K.; Tokuyama, M.; Hirota, H.; Muneuchi, J.; Higashinakagawa, T. & Matsuoka, R.

(2007). Germline gain-of-function mutations in RAF1 cause Noonan syndrome. *Nat Genet.*, Vol. 39, No. 8, 1013-1017

Reynolds, J.F.; Neri, G.; Herrmann, J.P.; Blumberg, B.; Coldwell, J.G.; Miles, P.V. & Opitz, J.M. (1986). New multiple congenital anomalies/mental retardation syndrome with cardio-facio-cutaneous involvement--the CFC syndrome. *Am. J. Med. Genet.*, Vol. 25, No. 3, 413-427

Riccardi, V.M. (1981). Von Recklinghausen neurofibromatosis. *N. Engl. J. Med.*, Vol. 305, No. 27, 1617-1627

Roberts, A.E.; Araki, T.; Swanson, K.D.; Montgomery, K.T.; Schiripo, T.A.; Joshi, V.A.; Li, L.; Yassin, Y.; Tamburino, A.M.; Neel, B.G. & Kucherlapati, R.S. (2007). Germline gain-of-function mutations in SOS1 cause Noonan syndrome. *Nat. Genet.*, Vol. 39, No. 1, 70-74

Rodriguez-Viciana, P.; Tetsu, O.; Tidyman, W.E.; Estep, A.L.; Conger, B.A.; Cruz, M.S.; McCormick, F. & Rauen, K.A. (2006). Germline mutations in genes within the MAPK pathway cause cardio-facio-cutaneous syndrome. *Science*, Vol. 311, No. 5765, 1287-1290

Rubinstein, J.H. & Taybi, H. (1963). Broad thumbs and toes and facial abnormalities. A possible mental retardation syndrome. *Am. J. Dis. Child.*, Vol. 105, 588-608

Rubinstein, J.H. (1990). Broad thumb-hallux (Rubinstein-Taybi) syndrome 1957-1988. *Am. J. Med. Genet.* Suppl., Vol. 6, 3-16

Rujescu, D.; Ingason, A.; Cichon, S.; Pietiläinen, O.P.; Barnes, M.R.; Toulopoulou, T.; Picchioni, M.; Vassos, E.; Ettinger, U.; Bramon, E.; Murray, R.; Ruggeri, M.; Tosato, S.; Bonetto, C.; Steinberg, S.; Sigurdsson, E.; Sigmundsson, T.; Petursson, H.; Gylfason, A.; Olason, P.I.; Hardarsson, G.; Jonsdottir, G.A.; Gustafsson, O.; Fossdal, R.; Giegling, I.; Möller, H.J.; Hartmann, A.M.; Hoffmann, P.; Crombie, C.; Fraser, G.; Walker, N.; Lonnqvist, J.; Suvisaari, J.; Tuulio-Henriksson, A.; Djurovic, S.; Melle, I.; Andreassen, O.A.; Hansen, T.; Werge, T.; Kiemeney, L.A.; Franke, B.; Veltman, J.; Buizer-Voskamp, J.E.; GROUP Investigators; Sabatti, C.; Ophoff, R.A.; Rietschel, M.; Nöthen, M.M.; Stefansson, K.; Peltonen, L.; St Clair, D; Stefansson, H. & Collier, D.A. (2009). Disruption of the neurexin 1 gene is associated with schizophrenia. *Hum. Mol. Genet.*, Vol. 18, No. 5, 988-996.

Sabatino, G.; Verrotti, A.; Domizio, S.; Angeiozzi, B.; Chiarelli, F. & Neri, G. (1997). The cardio-facio-cutaneous syndrome: a long-term follow-up of two patients, with special reference to the neurological features. *Childs Nerv. Syst.*, Vol. 13, No. 4, 238-241

Schubbert, S.; Zenker, M.; Rowe, S.L.; Böll, S.; Klein, C.; Bollag, G.; van der Burgt, I.; Musante, L.; Kalscheuer, V.; Wehner, L.E.; Nguyen, H.; West, B.; Zhang, K.Y.; Sistermans, E.; Rauch, A.; Niemeyer, C.M.; Shannon, K. & Kratz, C.P. (2006). Germline KRAS mutations cause Noonan syndrome. *Nat. Genet.,* Vol. 38, No. 3, 331-336. Erratum in: *Nat. Genet.*, Vol. 38, No. 5, 598

Schulz, A.L.; Albrecht, B.; Arici, C.; van der Burgt, I.; Buske, A.; Gillessen-Kaesbach, G.; Heller, R.; Horn, D.; Hübner, C.A.; Korenke, G.C.; König, R.; Kress, W.; Krüger, G.; Meinecke, P.; Mücke, J.; Plecko, B.; Rossier, E.; Schinzel, A.; Schulze, A.; Seemanova, E.; Seidel, H.; Spranger, S.; Tuysuz, B.; Uhrig, S.; Wieczorek, D.; Kutsche, K. & Zenker, M. (2008). Mutation and phenotypic spectrum in patients with cardio-facio-cutaneous and Costello syndrome. *Clin. Genet.*, Vol. 73, No. 1, 62-70

Sebat, J.; Lakshmi, B.; Malhotra, D; Troge, J.; Lese-Martin, C.; Walsh, T.; Yamrom, B.; Yoon, S.; Krasnitz, A.; Kendall, J.; Leotta, A.; Pai, D.; Zhang, R.; Lee, Y.H.; Hicks, J.; Spence, S.J.; Lee, A.T.; Puura, K.; Lehtimäki, T.; Ledbetter, D.; Gregersen, P.K.; Bregman, J.; Sutcliffe, J.S.; Jobanputra, V.; Chung, W.; Warburton, D.; King, M.C.; Skuse, D.; Geschwind, D.H.; Gilliam, T.C.; Ye, K. & Wigler, M. (2007). Strong association of de novo copy number mutations with autism. *Science*, Vol. 316, 445–449

Sharp, A.J.; Mefford, H.C.; Li, K.; Baker, C.; Skinner, C.; Stevenson, R.E.; Schroer, R.J.; Novara, F.; De Gregori, M.; Ciccone, R.; Broomer, A.; Casuga, I.; Wang, Y.; Xiao, C.; Barbacioru, C.; Gimelli, G.; Bernardina, B.D.; Torniero, C.; Giorda, R.; Regan, R.; Murday, V.; Mansour, S.; Fichera, M.; Castiglia, L.; Failla, P.; Ventura, M.; Jiang, Z.; Cooper, G.M.; Knight, S.J.; Romano, C.; Zuffardi, O.; Chen, C.; Schwartz, C.E. & Eichler, E.E. (2008). A recurrent 15q13.3 microdeletion syndrome associated with mental retardation and seizures. *Nat. Genet.*, Vol. 40, No. 3, 322-328

Shaw, A.C.; Kalidas, K.; Crosby, A.H.; Jeffery, S. & Patton, M.A. (2007). The natural history of Noonan syndrome: a long-term follow-up study. *Arch. Dis. Child.*, Vol. 92, No. 2, 128-132

Stefansson, H.; Rujescu, D.; Cichon, S.; Pietiläinen, O.P.; Ingason, A.; Steinberg, S.; Fossdal, R.; Sigurdsson, E.; Sigmundsson, T.; Buizer-Voskamp, J.E.; Hansen, T.; Jakobsen, K.D.; Muglia, P.; Francks, C.; Matthews, P.M.; Gylfason, A.; Halldorsson, B.V.; Gudbjartsson, D.; Thorgeirsson, T.E.; Sigurdsson, A.; Jonasdottir, A.; Jonasdottir, A.; Bjornsson, A.; Mattiasdottir, S.; Blondal, T.; Haraldsson, M.; Magnusdottir, B.B.; Giegling, I.; Möller, H.J.; Hartmann, A.; Shianna, K.V.; Ge, D.; Need, A.C.; Crombie, C.; Fraser, G.; Walker, N.; Lonnqvist, J.; Suvisaari, J.; Tuulio-Henriksson, A.; Paunio, T.; Toulopoulou, T.; Bramon, E.; Di Forti, M.,; Murray, R.; Ruggeri, M.; Vassos, E.; Tosato, S.; Walshe, M.; Li, T.; Vasilescu, C.; Mühleisen, T.W.; Wang, A.G.; Ullum, H.; Djurovic, S.; Melle, I.; Olesen, J.; Kiemeney, L.A.; Franke, B.; GROUP; Sabatti, C.; Freimer, N.B.; Gulcher, J.R.; Thorsteinsdottir, U.; Kong, A.; Andreassen, O.A.; Ophoff, R.A.; Georgi, A.; Rietschel, M.; Werge, T.; Petursson, H.; Goldstein, D.B.; Nöthen, M.M.; Peltonen, L.; Collier, D.A.; St Clair, D. & Stefansson, K. (2008) Large recurrent microdeletions associated with schizophrenia. *Nature*, Vol. 455, 232–236

Subramanian, G.; Adams, M.D.; Venter, J.C. & Broder, S. (2001). Implications of the human genome for understanding human biology and medicine. *JAMA*, Vol. 286, No. 18, 2296-2307

Tarpey, P.S.; Smith, R.; Pleasance, E.; Whibley, A.; Edkins, S.; Hardy, C.; O'Meara, S.; Latimer, C.; Dicks, E.; Menzies, A.; Stephens, P.; Blow, M.; Greenman, C.; Xue, Y.; Tyler-Smith, C.; Thompson, D.; Gray, K.; Andrews, J.; Barthorpe, S.; Buck, G.; Cole, J.; Dunmore, R.; Jones, D.; Maddison, M.; Mironenko, T.; Turner, R.; Turrell, K.; Varian, J.; West, S.; Widaa, S.; Wray, P.; Teague, J.; Butler, A.; Jenkinson, A.; Jia, M.; Richardson, D.; Shepherd, R.; Wooster, R.; Tejada, M.I.; Martinez, F.; Carvill, G.; Goliath, R.; de Brouwer, A.P.; van Bokhoven, H.; Van Esch, H.; Chelly, J.; Raynaud, M.; Ropers, H.H.; Abidi, F.E.; Srivastava, A.K.; Cox, J.; Luo, Y.; Mallya, U.; Moon, J.; Parnau, J.; Mohammed, S.; Tolmie, J.L.; Shoubridge, C.; Corbett, M.; Gardner, A.;

Haan, E.; Rujirabanjerd, S.; Shaw, M.; Vandeleur, L.; Fullston, T.; Easton, D.F.; Boyle, J.; Partington, M.; Hackett, A.; Field, M.; Skinner, C.; Stevenson, R.E.; Bobrow, M.; Turner, G.; Schwartz, C.E.; Gecz, J.; Raymond, F.L.; Futreal, P.A. & Stratton, M.R. (2009). A systematic, large-scale resequencing screen of X-chromosome coding exons in mental retardation. *Nat. Genet.*, Vol. 41, No. 5, 535-543

Tartaglia, M.; Mehler, E.L.; Goldberg, R.; Zampino, G.; Brunner, H.G.; Kremer, H.; van der Burgt, I.; Crosby, A.H.; Ion, A.; Jeffery, S.; Kalidas, K.; Patton, M.A.; Kucherlapati, R.S. & Gelb, B.D. (2001). Mutations in PTPN11, encoding the protein tyrosine phosphatase SHP-2, cause Noonan syndrome. *Nat. Genet.*, Vol. 29, No. 4, 465-468; Erratum in: (2001). *Nat. Genet.*, Vol. 29, No. 4, 491 and (2002). *Nat. Genet.*, Vol. 30, No. 1, 123

Tartaglia, M.; Kalidas, K.; Shaw, A.; Song, X.; Musat, D.L.; van der Burgt, I.; Brunner, H.G.; Bertola, D.R.; Crosby, A.; Ion, A.; Kucherlapati, R.S.; Jeffery, S.; Patton, M.A. & Gelb, B.D. (2002). PTPN11 mutations in Noonan syndrome: molecular spectrum, genotype-phenotype correlation, and phenotypic heterogeneity. *Am. J. Hum. Genet.*, Vol. 70, No. 6, 1555-1563

Tartaglia, M.; Pennacchio, L.A.; Zhao, C.; Yadav, K.K.; Fodale, V.; Sarkozy, A.; Pandit, B.; Oishi, K.; Martinelli, S.; Schackwitz, W.; Ustaszewska, A.; Martin, J.; Bristow, J.; Carta, C.; Lepri, F.; Neri, C.; Vasta, I.; Gibson, K.; Curry, C.J.; Siguero, J.P.; Digilio, M.C.; Zampino, G.; Dallapiccola, B.; Bar-Sagi, D.; Gelb, B.D. (2007). Gain-of-function SOS1 mutations cause a distinctive form of Noonan syndrome. *Nat. Genet.*, Vol. 39, No. 1, 75-79. Erratum in: *Nat. Genet.*, Vol. 39, No. 2, 276

Tidyman, W.E. & Rauen, K.A. (2008). Noonan, Costello and cardio-facio-cutaneous syndromes: dysregulation of the Ras-MAPK pathway. *Expert Rev. Mol. Med.*, Vol. 10, e37

Tidyman, W.E. & Rauen, K.A. (2009). The RASopathies: developmental syndromes of Ras/MAPK pathway dysregulation. *Curr. Opin. Genet. Dev.*, Vol. 19, No. 3, 230-236

Trivier, E.; De Cesare, D.; Jacquot, S.; Pannetier, S.; Zackai, E.; Young, I.; Mandel, J.-L.; Sassone-Corsi, P.; Hanauer, A. (1996). Mutations in the kinase Rsk-2 associated with Coffin-Lowry syndrome. *Nature*, Vol. 384, 567-570

Van Bon, B.W.; Mefford, H.C.; Menten, B.; Koolen, D.A.; Sharp, A.J.; Nillesen, W.M.; Innis, J.W.; de Ravel, T.J.; Mercer, C.L.; Fichera, M.; Stewart, H.; Connell, L.E.; Ounap, K.; Lachlan, K.; Castle, B.; Van der Aa, N.; van Ravenswaaij, C.; Nobrega, M.A.; Serra-Juhé, C.; Simonic, I.; de Leeuw, N.,; Pfundt, R.; Bongers, E.M.; Baker, C.; Finnemore, P.; Huang, S.; Maloney, V.K.; Crolla, J.A.; van Kalmthout, M.; Elia, M.; Vandeweyer, G.; Fryns, J.P.; Janssens, S.; Foulds, N.; Reitano, S.; Smith, K.; Parkel, S.; Loeys, B.; Woods, C.G.; Oostra, A.; Speleman, F.; Pereira, A.C.; Kurg, A.; Willatt, L.; Knight, S.J.; Vermeesch, J.R.; Romano, C.; Barber, J.C.; Mortier, G.; Pérez-Jurado, L.A.; Kooy, F.; Brunner, H.G.; Eichler, E.E.; Kleefstra, T. & de Vries, B.B. (2009). Further delineation of the 15q13 microdeletion and duplication syndromes: a clinical spectrum varying from non-pathogenic to a severe outcome. *J. Med. Genet.*, Vol. 46, No. 8, 511-523

Van Steensel, M.A.; Vreeburg, M.; Peels, C.; van Ravenswaaij-Arts, C.M.; Bijlsma, E.; Schrander-Stumpel, C.T. & van Geel, M. (2006). Recurring HRAS mutation G12S in Dutch patients with Costello syndrome. *Exp. Dermatol.*, Vol. 15, No. 9, 731-734

Viskochil, D.; Buchberg, A.M.; Xu, G.; Cawthon, R.M.; Stevens, J.; Wolff, R.K.; Culver, M.; Carey, J.C.; Copeland, N.G.; Jenkins, N.A.; White, R. & O'Connell, P. (1990). Deletions and a translocation interrupt a cloned gene at the neurofibromatosis type 1 locus. *Cell*, Vol. 62, No. 1, 187-192

Wassink, T.H.; Piven, J. & Patil, S.R. (2001). Chromosomal abnormalities in a clinic sample of individuals with autistic disorder. Psychiatr. Genet., Vol. 11, 57–63

Weeber, E.J.; Levenson, J.M. & Sweatt, J.D. (2002). Molecular genetics of human cognition. *Mol. Interv*., Vol. 2, No. 6, 376-391

Wieczorek, D.; Majewski, F. & Gillessen-Kaesbach, G. (1997). Cardio-facio-cutaneous (CFC) syndrome--a distinct entity? Report of three patients demonstrating the diagnostic difficulties in delineation of CFC syndrome. *Clin. Genet*., Vol. 52, No. 1, 37-46

Williams, H.J.; Owen, M.J. & O'Donovan, M.C. (2009). Schizophrenia genetics: new insights from new approaches. *Br. Med. Bull*., Vol. 91, 61-74

Xing, J.; Ginty, D.D. & Greenberg, M.E. (1996). Coupling of the RAS-MAPK pathway to gene activation by RSK2, a growth factor-regulated CREB kinase. *Science*, Vol. 273, No. 5277, 959-963

Yoon, G.; Rosenberg, J.; Blaser, S. & Rauen, K.A. (2007). Neurological complications of cardio-facio-cutaneous syndrome. *Dev. Med. Child Neurol*., Vol. 49, No. 12, 894- 899

Yoon, S. & Seger, R. (2006). The extracellular signal-regulated kinase: multiple substrates regulate diverse cellular functions. *Growth Factors*, Vol. 24, No. 1, 21-44

Young, T.L.; Ziylan, S. & Schaffer, D.B. (1993). The ophthalmologic manifestations of the cardio-facio-cutaneous syndrome. *J. Pediatr. Ophthalmol. Strabismus*., Vol. 30, No. 1, 48-52

Zampino, G.; Pantaleoni, F.; Carta, C.; Cobellis, G.; Vasta, I.; Neri, C.; Pogna, E.A.; De Feo, E.; Delogu, A.; Sarkozy, A.; Atzeri, F.; Selicorni, A.; Rauen, K.A.; Cytrynbaum, C.S.; Weksberg, R.; Dallapiccola, B.; Ballabio, A.; Gelb, B.D.; Neri, G. & Tartaglia, M. (2007). Diversity, parental germline origin, and phenotypic spectrum of de novo HRAS missense changes in Costello syndrome. *Hum. Mutat*., Vol. 28, No. 3, 265-272

Zahir, F.R.; Baross, A.; Delaney, A.D.; Eydoux, P.; Fernandes, N.D.; Pugh, T.; Marra, M.A. & Friedman, J.M. (2008). A patient with vertebral, cognitive and behavioural abnormalities and a de novo deletion of NRXN1alpha. *J. Med. Genet*., Vol. 45., No. 4, 239-243

Zenker, M.; Lehmann, K.; Schulz, A.L.; Barth, H.; Hansmann, D.; Koenig, R.; Korinthenberg, R.; Kreiss-Nachtsheim, M.; Meinecke, P.; Morlot, S.; Mundlos, S.; Quante, A.S.; Raskin, S.; Schnabel, D.; Wehner, L.E.; Kratz, C.P.; Horn, D. & Kutsche, K. (2007). Expansion of the genotypic and phenotypic spectrum in patients with KRAS germline mutations. *J. Med. Genet*., Vol. 44, No. 2, 131-135

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