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Edy Portmann
Marco E. Tabacchi
Rudolf Seising
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Designing Cognitive Cities

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Designing Cognitive Cities

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Foreword

It is not easy to write a meaningful preface to a book which is as ambitious and as unconventional as this book is. Its focus is cognitive science and soft computing—a sphere of human cognition which was born with the computer age. Around the middle of last century, I witnessed the birth. The source of excitement was Artificial Intelligence (AI). There were many exaggerated expectations which were promoted by the AI leaders John McCarthy, Marvin Minsky, Allen Newell, and others. I was just beginning my teaching career and was enthuse by what I saw and heard. My first paper was "Thinking machines—a new field in electrical engineering" published in January 1950 (Zadeh 1950), in Columbia Engineering Quarter. In this paper, I started with a list of headlines which appear in the popular press at that time, for example, "An electrical machine capable of translating foreign languages is being built." What is remarkable is that today, many years later, we still do not have machines which are close to delivering, close to human quality machine translation. Exaggerated expectations were fueled by quest by financial support. It was a game which AI paid dearly with many long month of winter from which it is beginning to emerge.

In my view, the pioneers of AI made a major mistake. They put all of the AI's eggs into the basket of classical logic and turning away from anything that was not logic base. What they overlooked was that much of everyday human reasoning—the reasoning which underlies cognitive science and soft computing is not based on classical logic. In particular, fuzzy logic on approximate reasoning plays essential roles in human reasoning and human cognition. For many years, the AI community took a very skeptical position on anything that was not based on classical logic—fuzzy logic numerical computations. Neurocomputing, evolutionary computing, and probability theory—methodologies which are at the center of what successful AI is today. For me, the best example of successful AI is the "smart" phone. The smart phone is indeed a remarkable product which was science fiction not that long ago.

Approximate reasoning underlies much of human reasoning, cognitive science, and soft computing. In approximate reasoning, the optic of reasoning and computation are for the most part is fuzzy sets, that is, classes which unsharp (fuzzy) borders. This is what traditional AI overlooked. It will take many Ph.D. theses on over a long period of time to develop what could be justifiably called a unified theory of inexact and approximate reasoning. Today, all we have are fragments. The mathematics of approximate reasoning is much more complex than the mathematics exact reasoning. In fact, the mathematics of inexact and approximate reasoning will be a new kind of mathematics. It would be much more computer-oriented than what mathematics is today.

I should like to put on the table a new concept—invaluent variable. In large measure, computation involves assignment of values to variables. In realistic settings, there are many situations in which we cannot assign a value to a variable X because we do not know what the value is and do not have a clear idea how it can be define, for example, variables which related to fairness, rationality, beauty, and relevance. Variables of this kind are invaluent variables, and the underlying issue is invaluence. Invaluence is pervasive in cognitive science, cognitive computer, and approximate and inexact reasoning. In the context of invaluency in large measure, we are dealing with perceptions rather than measurements. If X is an invaluent variable, a value which can be assign to X is a Z-number (Zadeh 2011). A Z-number is a construct with three components. The first component is the name of the variable. The second component called "value" is an estimated value of X, based mostly on perception-based information. The third component called "confidence" is a fuzzy number which is an estimate of the goodness/correctness/reliability of A as an estimate of X, for example, first component: projected deficit; second component: about $ 5,000,000; third component: high is a linguistic description of a fuzzy number. For simplicity, linguistic fuzzy numbers are assumed to be high, medium, and low. Fuzzy numbers can be computed with a recent groundbreaking monograph by Rafik (2016).

In coming years, I envisage that theories of fuzzy numbers and their applications will grow invisibility and importance. It may turn out that the concept of a Z-number is what is needed to develop cognitive science, cognitive computer, and inexact and approximate reasoning. The importance of Z-numbers derives from the fact that they can be computed with and reason with logically.

Berkeley, CA, USA
October 2016

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[1] The author of this Foreword, Professor emeritus Dr. Lotfi A. Zadeh, world-renowned computer scientist and source of the author's and editor's curiosity, died on September 06, 2017, at the age of 96. He will be greatly missed. His obituary at UC Berkeley may be found at: https://engineering.berkeley.edu/2017/09/remembering-lotfi-zadeh. Accessed March 01, 2018.

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Part I
Introduction

Designing Cognitive Cities

Marco E. Tabacchi, Edy Portmann, Rudolf Seising and Astrid Habenstein

Abstract The following text intends to give an introduction into some of the basic ideas which determined the conception of this book. Thus, the first part of this article introduces the terms "City", "Smart City" and "Cognitive City". The second part gives an overview of design theories and approaches such as Action Design Research and Ontological Design (a concept in-the-making), in order to deduce from a theoretical point of view some of the principles that needs to be taken into account when designing the Cognitive City. The third part highlights some concrete techniques that can be usefully applied to the problem of citizen communication for Cognitive Cities (namely Metaheuristics, Fuzzy Sets and Fuzzy Logic, Computing with Words, Computational Intelligence Classifiers, and Fuzzy-based Ontologies). Finally, we introduce the articles of this book.

Keywords Action Design Research (ADR) · Cognitive city
Collective intelligence—urban intelligence · Computational intelligence
Citizen communication · Computing with words · Fuzzy logic
Ontological design · Smart city

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1 From Smart to Cognitive Cities

1.1 The City in the Age of Globalization

The city is (and always was) a complex, multifaceted phenomenon. There are numerous scientific approaches and disciplines dealing with its dimensions and, accordingly, widely varying ideas about what constitutes the city (Mieg 2013). Not least due to this fact, it seems almost impossible to give the term “city” one universal, scientifically substantiated and comprehensive definition—and perhaps it does not even make sense to try to find one as this would be rather superficial (Eckardt 2014). However, most definitions and description have in common that they usually associate or postulate two general perspectives as central to describe the city appropriately, thus describing the reference framework and fields of action for a sustainable urban development: the spatial-material and the social-cultural dimension. In a very general sense, cities are almost always considered as topographically describable and geographically definable places with characteristic, condensed settlements and infrastructures, which separate the city from the non-urban surrounding area (with fluent transitions); they are places where a large number of different people live, work, create specific forms of life and, despite all heterogeneity, also develop a common identity (Mieg 2013).

In this sense, the city has been for millennia a settlement structure and way of life which is typical and of great importance to mankind. And it gets even more important: Since the beginning of the 20th century, the world population has quadrupled to about 7.4 billion people in 2015, and in its most recent population report, the UN estimates that in 2030 ca. 8.5 billion and in 2050 ca. 9.1 are going to live on planet Earth (United Nations 2015). This development is accompanied by a process of accelerated urbanization: In 1950 more than 70% of the world’s population still lived in rural regions. In 2007, for the first time the urban population was larger than the rural population, and the UN’s latest estimates assume that in 2050 66% of all people are going to be inhabitants of cities. The regional differences here are sometimes immense: in North and Latin America already 84%, in Europe 73%, while in Africa and Asia still less than half of the population live in cities (United Nations 2014). But the general trend is tangible everywhere.

Sometimes this is regarded as sign of progress, as life in the city can allow more spiritual, cultural and social growth, as well as better living conditions and levels of care. But as we all know this does not necessarily hold true everywhere: Today’s cities struggle with the repercussions of the rapid growth of population (and simultaneously decreasing availability of living spaces) as well as globalization, climate change, the increasing scarcity of natural resources and the so-called Third (or Fourth) Industrial Revolution. So-called megacities (with more than 10 million inhabitants, such as New York, Tokyo, Manila, Beijing, Rio de Janeiro or Mumbai), whose number has risen from 10 to 28 since 1990 (United Nations 2014), are symbols of the consequences of an urbanization that is barely controllable under the conditions of globalization. And these trends are also tangible in the relatively small cities of Western Europe, though not nearly as bad as in the megacities of Asia and Latin America. European cities become larger and more complex, too, and their heavily used infrastructures are increasingly coming up against their load limits. Environmental issues; the integration of different cultures and traditions; healthcare and quality of life, especially for the elders and disabled; pollution; eco-compatible transport and working policies—these are but some of the problems modern cities have to deal with worldwide.

These developments are going to change the relationship between citizen and city immensely. Therefore, it is more important than ever before to think about how cities have to be shaped to provide their inhabitants with the means and resources for a good life. One approach to deal with the challenges of modern cities is associated with the buzzword "Smart City".

1.2 Smart City–Cognitive City

There are a lot of perspectives, research approaches and, subsequently, lots of definitions and conceptions of the term "Smart City" (Albino et al. 2015). But all of them have in common the basic idea that the enrichment of city-relevant functions with ICT can contribute to develop efficiently and sustainably the socioecological design of the urban space (Portmann and Finger 2015). The collection and analysis of city-related data as well as the coordination of their use by means of internet and web-based services are intended to help to develop cities into better, more beautiful, more viable places.

The challenges cities have to deal with and for which smart solutions proved to be especially suitable are often very similar, albeit with different focuses, depending on the specific character, problems and needs of the city in question. In general, smart solutions are applied to subjects such as smart mobility, smart energy, smart environment, smart economy, smart living, and smart governance. Hereby, Smart City-concepts and -projects tend to focus on the enhancement of efficiency and sustainability. Especially with respect to transport and mobility, (public) security, environmental and climate protection (waste management, resource-efficient use of energy and water), and municipal administration services there are impressive possibilities to make use of ICT to meet the challenges in the city (Townsend 2013).

Nonetheless, there are also critics with well-founded demurs against the Smart City. Recently, the discussion turns towards two aspects: Firstly, critics point out the problem that Smart City-initiatives are too often planned "top-down" (Cohen 2015; Dyer et al. 2017). Secondly, it becomes apparent that the focus on efficiency and sustainability is expedient and very important in many respects, but in certain cases not the best way to deal with the needs of the individual (Finger and Portmann 2016). Therefore, the legitimate claim of the citizens to participate in shaping their cities and communities and the human need to be perceived as individuals attracts more and more awareness (Dyer et al. 2017; Beinrott 2015). The Cognitive City-approach is supposed to address these requirements.

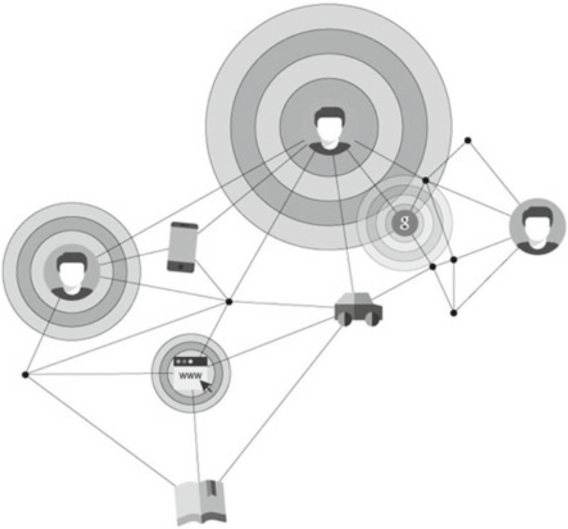

Fig. 1 Connectivism (following Siemens 2006)

The main-characteristic of smart cities is the collection, analysis and preparation of data to obtain information that can be used to address specific problems or needs in the city (Finger and Portmann 2015). A city can become smarter by collecting high-quality data made available to the various stakeholders of a city (Hurwitz et al. 2015). Thus, they are able to better deal with specific problems or needs in the city. Therefore, it is imperative to build up and to make use of the "urban intelligence", the collective intelligence of the city.

Collective intelligences consist of individual intelligences: more or less intelligent human beings as well as more or less intelligent objects such as Artificial Intelligences (AI) or electronic devices. They form a network that is more than the sum of its elements and contributes to problem solving differently than individual intelligences would (Malone and Bernstein 2015). The "glue" that connects them can be described best as "connectivism", in reference to the eponymous learning and cognition theory by Siemens (2006). In contrast to conventional theories such as behaviorism, cognitivism and constructivism, the "Connected Learning Theories" (Caine and Caine 2011; Ito et al. 2013) and the "Incidental Connectivism" (Siemens 2006) understand learning as a process in which the learning subject—or object!—forms networks by linking to nodes. Nodes can be other people, but also databases, apps, the Internet, smartphones, books, images, etc., which have their own networks that the learning subject/object also accesses by connecting to the corresponding node (Fig. 1). Their diversity and the diversity of their networks help to generate knowledge that extends the original knowledge, or even goes beyond it (Siemens 2006). The linking of nodes occurs by interaction and communication.

Cognitive City-approaches focus on the last aspect. The term refers to a continually interconnecting and exchanging web of information and communication hubs that lies at the core of tomorrow's (and today's) cities. In the Cognitive City the human factor is added to the communication loop, and communication between persons and persons, persons and machines and machines and machines constantly happens through any available means. The technical basis are cognitive computer systems, which are capable of recognizing patterns in the huge amounts of data and learn by interacting and communicating with the people who use them (Hurwitz et al. 2015; Wilke and Portmann 2016). At the same time, they are able to learn more about what we feel, want, and need, from the constant interaction with the people who use it. In this way, new data are collected and processed. Developments such as cloud-based social feedback, crowdsourcing, and predictive analytics allow cities to actively and independently learn, build, search, and expand when new information is added to the already existing ones.

Big Data and the Internet of Things (IoT), a network of objects that are equipped with sensors, software and network connectivity, are going to play an increasingly important role here (Townsend 2013). The objects are capable to collect and forward large amounts of data cost- and energy-efficiently, as well as exchanging them autonomously among themselves. Furthermore, the objects are capable of cooperating with existing Internet infrastructures. The entire urban environment is equipped with sensors that collect data which are made available in a cloud. Thus, every public implement is at the same time a useful fixture per se, and a fast, cheap and ubiquitous mean of data gathering, based on sensors and integrating actuators and distributed intelligent components via an extended mesh of mobile and static sharing points. This creates a permanent interaction between urban residents and the surrounding technology.

Cognitive City-concepts are not supposed to and cannot replace Smart City-approaches but complement them by focusing on a specific aspect of the Smart City: interaction and communication between the stakeholders and the city. Thus, the Cognitive City is not merely another topic such as smart mobility or smart energy, but another *perspective* that affects the Smart City as a whole: Cognitive City principles (as well as techniques resp. technologies) are applicable to all issues of the Smart City if it concerns aspects of interaction and communication. As said before, Cognitive City aims to answer demands of the future cities that cannot be met by the means of efficiency and sustainability only, but also address resilience as well as the citizens need for participation and individualism. Therefore, designing cognitive cities means designing the reciprocity of communication resp. interaction between city-related ICT and the citizens.

2 Designing Cognitive Cities

2.1 Theories of Design

No other species shaped planet Earth as much as humans did. The ability to transform and thus to "design" our natural, material and social environment according to our needs is not always positive but seems to be an essential part of human nature.

Marx (1867) spoke of the “toolmaking animal”, a conception that Bergson (1907) and Scheler (1926) transformed in the famous phrase “Homo faber”, which has since found its way into philosophical anthropology (Ropohl 2010). However, the ideas on how to define the term “design” vary widely (Mareis 2014). It was not until the nineteenth century that it gained the basic semantic content it has today: the preparatory, modelling process and its result, the designed artefact (Walker 1989; Hirdina 2010). Ever since, a vivid theoretical discussion emerged that is characterized by expanding the object of designing processes far beyond the traditional meaning of design as professionalized forms of handicraft, respectively technical drafting. Currently, the concept encompasses a general understanding of technical and organizational planning, conceptualizing and problem solving, too (Mareis 2014). Already at the end of the 1960s, Herbert A. Simon declared in his renowned book “The Science of the Artificial”: “Everyone designs who devises courses of action aimed at changing existing situations in preferred ones” (Simon 1969). This assertion is cited in virtually every publication on design theory and expresses that design can be everything that changes an instantaneous, unsatisfactory state for the better (Mareis 2014). In this sense, design is the practice of transforming the present and shaping the future.

One of the earliest debates in design theories about what design is (or should be), its purposes and principles as well as social, economic, scientific, philosophical or pragmatic implications started from the question what constitutes “good” design. The debate concentrated on the relationship between form and function; distancing from traditional concepts of aesthetics as measurement of the quality of design, it was argued that the design of an object is “good” (even beautiful), if it is functional. But since the 1960s, the technocratic and rationalistic tendency of this point of view was increasingly scrutinized. Critics argued that the rather lopsided orientation of design to questions of usefulness and functionality does not necessarily correspond to man’s need. As a consequence, they called for human centered design. The focus shifted from the categories of usefulness and functionality to the perception, reception and usage of design artefacts as well as their role as carriers and intermediaries of meaning. Subsequently, theorists of design got interested in the actors of the design process as well as the impact of their social, cultural, economic or political environment (Mareis 2013). An important contribution to these discussions provided the so-called “semantic turn” in design theory (Krippendorff 2006). Emphasizing the significance of the users as active participants in the design process, Krippendorff pointed out that designers should not only reproduce their own concepts of design, aesthetics and usability, but also respect the conceptions, values and knowledge of all who are affected by the artefacts. Human centered design requires an understanding that integrates recursively the understanding of others into one’s own.

And who designs? Simon (1969) declared that everyone could be a designer, not only scientists and engineers. Today, researchers go some steps further: To Rittel (1987) design is goal-oriented and reason-based problem-solving resp. decision-making. In this view, planning and thus designing is supposed to be an argumentative process that should not be conducted as closed scientific expert discourses, but participatory. Therefore, Rittel proposes—at least regarding “wicked problems" (very complex problems in the field of sociopolitical planning)—to replace the "expert model" with a "conspirative planning model" (Rittel 2013). In addition to the traditional view on designers and users as actors in design processes, theories of design that were influenced by the Actor-Network-Theory suggest taking into account the impact of inanimate artefacts as non-human actors, too (Mareis 2013). These concepts assume that artefacts have their own forms of material-visual communication and interaction that enables human and non-human actors to develop networks and thus to generate meaning and knowledge together.

Another important matter of subject in the theoretical debates is the relationship between design and knowledge, respectively the notion of design as epistemic practice. This aspect was discussed intensively since the 1960s, when Simon realized that artificiality was a prominent feature of modernity: "The world in which we live today is far more of a man-made or artificial than a natural world" (Simon 1969). Therefore, he called for the establishment of a new "science of the artificial" to deal adequately with artificially created objects and phenomena of information technologies. He regarded design as a scientific method of practical thought, planning, decision-making and anticipated that the production of scientific-technological knowledge necessarily and increasingly would take place in application- and design-oriented contexts, thus overcoming the borders between "science" and "practice". In this view, design produces specific forms of knowledge that are different from the conventional forms of knowledge production in the natural sciences or the humanities. Today, design research does not mean to explore design practice with scientific methods, but to generate new knowledge with the means and methods of design practice itself. The interplay of implicit, objectified and technical forms of procedures and knowledge forms an "epistemology of design" that focuses on design practices themselves (Mareis 2011).

To sum it up, debates on design theory are strongly influenced by the following key points: (1) technology-driven design principles versus the ideal of human centered design; (2) design as a sociocultural process; (3) the actors (the users as active participants in the design process; designing as argumentative practice that should not be conducted solely by experts; the impact of inanimate artefacts as non-human actors); (4) the 'epistemology of design' (designing produces specific forms of knowledge). All of these aspects are also relevant for designing the future city and should be part of concepts for smart und cognitive cities, too. Some of this is already discussed in information systems research, especially but not exclusively regarding design as epistemic practice. An important approach is Design Science Research (DSR), a set of synthetic and analytical techniques helping researchers to create new knowledge through designing respectively building ("knowledge through making") and analyzing the use and/or performance of artefacts along with reflection and abstraction. The aim is "to improve and understand the behavior of aspects of Information Systems" (Vaishnavi and Kuechler 2015). An interesting advancement and concrete proposal how to implement the principles of DSR is Action Design Research (ADR).

2.2 Action Design Research and Ontological Design

ADR is appreciated as a concept that tries to bring research and practice into the best possible exchange and combines design science with action research (Sein et al. 2011). In this view IT-artefact are "ensemble artefacts" originating from the interplay of design and the context in which design takes place (Gregor and Jones 2007). Thus, a research method is required that explicitly regards artefacts as ensembles "emerging from design, use, and ongoing refinement in an organizational context", which are shaped by the "interests, values and assumptions of a wide variety of communities of developers, investors and users" (Orlikowski and Iacono 2001, p. 131; Sein et al. 2011, p. 38). Building and evaluating ensemble IT artefact culminate in prescriptive design knowledge.

ADR-projects consist of four stages encompassing principles and specific tasks for every stage (Fig. 2). In Stage One ("Problem Formulation") the research question, methodology and research design are developed. Stage One is characterized by two principles: "Practice-Inspired Research" and "Theory ingrained artefact". The combination of these principles enables to connect better research and practice: By the means of scientific theory formation the solution for a concrete field-problem that is regarded as "knowledge-creation opportunity" can be described exactly and an appropriate prototype can be developed, providing the basis for cycles of "Building, Intervention and Evaluation" (BIE) in Stage Two. In Stage Two this initial design is further shaped by organizational use and subsequent design cycles. The elements of the iterative process are intertwined with constant evaluation. Reciprocal shaping, mutually influential roles, and evaluation are the leading principles of this stage to ensure this and to intensify the mutual learning of the ADR-partners.

Stage Three is about "Reflection and Learning". This phase represents the step from building a solution for a particular problem to apply the results of the research process to a broader class of problems, an important characteristic of ADR: ADR-teams do not intend to solve only one specific problem, or to intervene within the organizational context of the problem, they aim to generate knowledge that can

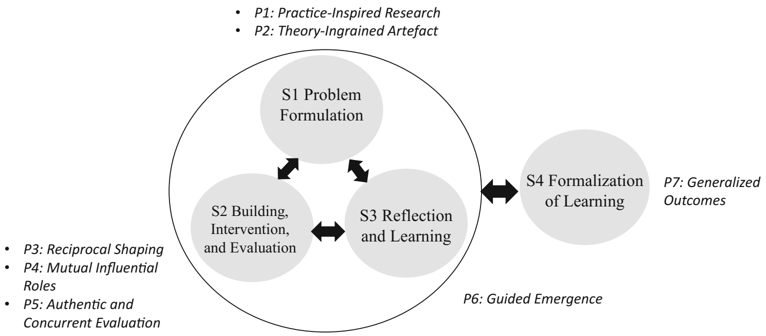

Fig. 2 Stages (S) and Principles (P) of ADR (following Sein et al. 2011, 41)

be applied to the class of problems that the specific problem exemplifies. Hereby, the ensemble artefact “will reflect not only the preliminary design created by the researchers but also its ongoing shaping by organizational use, perspectives, and participants” (Sein et al. 2011; Iivari 2007). Any Observations, changes to the artefact or anticipated as well as unanticipated consequences during the BIE iterations needs to be reflected. These observations are the basis to “Formalize the Learning” and to derive “Design Principles” in Stage Four. This phase draws on the principle that generalized outcomes are a critical component of ADR. The researchers outline the accomplishments realized in the IT-artefact and describe their results on three levels: generalizing the problem, generalizing the solution, and deriving the Design Principles that connects the generalized outcomes to a class of solutions and a class of problems.

Currently, ADR gains more and more attention and proponents, and there are first (more or less theoretical) attempts, too, to apply the idea to Smart City-projects (Maccani et al. 2014a, b; Ståhlbröst et al. 2015a, b). There are several reasons that makes ADR interesting for the Cognitive City. On the one hand, this applies to the point of view of creating a methodological and organizational framework in which different groups of vehicles are linked. A similar framework is also needed for the development of the smart and cognitive cities. There are numerous stakeholders that want to take part in the project of designing their cities. In addition, principles of transdisciplinarity could be better implemented, thus ensuring that new insights from research and development are better being disseminated and applied in the “real world”. Simultaneously, the data base increases, which in turn can be used for new developments. In addition, action research elements appear particularly promising in such an application-oriented area of development and research as the Smart City. However, there remain also some difficulties, especially if ADR should be applied to Cognitive Cities.

A research approach is needed to adjust the basics of ADR to the framework that characterizes the Cognitive City. Therefore, we want to outline first theoretical considerations on principles for Ontological Design Research (ODR), a research method in the making which is based on ADR, but focusses on the particularities regarding the user, the context and the artefact in sociotechnical systems like the Cognitive City. Hereby the notion “We shape our world as this world affects and shapes us” (Willis 2006) can be considered as the basic idea of ontological design.

1. The user and the context: The primary goal of ADR is not to integrate the user into the design-process in the sense of human-centered design. ADR was originally made to improve the cooperation between research and practice by implementing design knowledge methods and focusing on the artefact and its context. This does not mean at all that the (individual) human beings are unimportant to ADR, on the contrary. But the human factor appears as one aspect among others which belong to the context of an IT-artefact. However, to retrieve the full potential of the user as co-researcher and co-designer something more needs to be done especially as the call for IT-projects that take the user into account und ask them what they want gets louder. Furthermore, it is relatively difficult to capture the so-called ADR-team in the concept. This is plausible

insofar as it is difficult to generalize the composition, roles and tasks, for this may differ very much from project to project. Unfortunately, it is even harder to capture the roles and functions of the end-user in ADR-projects. Of course, they appear in Seins BIE-schemata, but not as member of the ADR-team (Sein et al. 2011), and the description of their role and functions stays rather superficial. Next to this, it remains somewhat unclear what constitutes an "organizational context" and how to deal with the differences between the various possible contexts.

All of it is less problematic in small, well-defined organizational contexts, especially if practitioners and/or researchers are simultaneously the end-user. However, in the complex situation of a Cognitive City with lots of subsystems and -contexts, stakeholders, interest groups and individuals this will not work. It is paramount to address explicitly the end-user in concepts for designing Cognitive Cities as this aspect touches one of its main promises: the involvement of the citizen in shaping the city, and it is necessary to sharpen the ADR-concept as it is to be expected that different organizational contexts need different ADR-concepts.

2. The artefact: Traditionally, artefacts are thought to be relatively passive in the process of development and design. However, as mentioned above, recent theories of design that were influenced by the Actor-Network-Theory suggest taking into account the impact of inanimate artefacts as non-human actors, too. This idea helps to conceptualize the role of artificial intelligence in human-centered systems like the Cognitive City: The Cognitive City-concept refers to the reciprocity of communication resp. interaction between city-related ICT and the citizens and can encompass all aspects of life in the city. The instrument to implement this idea are self-learning cognitive systems. Here, the artefact supposed to develop action-impulses by its own by collecting information and processing them independently to new knowledge. Regarding the Cognitive City, it is necessary to include in ODR the idea that artefacts are not only designed in an iterative process, but that they also have a creative effect in said process—and vice versa.

3 Designing Citizen Communication

3.1 Computational Intelligence and Citizen Communication

In the present volume the reader will find a number of contributions, both theoretical and practical, toward the successful building of a Cognitive City using techniques and methodologies from computational intelligence. The technical and theoretical aspects of such research are paramount toward the objective of a Cognitive City, but as important is the human dialogue factor: for the foreseeable future, and up to the eventual singularity (Tabacchi 2013), humans will continue to dialogically negotiate many of the aspects related to social life, in cities and elsewhere, using written and oral language and expecting as well to interact with the same means in the public discourse. As such, one important element of the development of cognitive cities will be related to automatic speech and written language recognition, on the models with which such semantization will represent the respective ontologies, as well as on the constant connection and correlation between the data captured from ubiquitous sensors and the legitimate requests for participation in the decisional process expressed through natural language. All these processes go under the name of citizen communication (Perticone and Tabacchi 2016; D'Asaro et al. 2017), and in our opinion they will be fundamental in the attainment of the main goals of all the projects in the general area of Cognitive Cities.

The ability of cognitive systems to deal with verbal and non-verbal forms of human communication is essential in the Cognitive City. Building the 'smart' components of a Cognitive City, e.g. the network of sensors, actuators and the communication infrastructure that presides to them, requires a number of advancements in electronics, miniaturization and big data handling. The problem of dealing with human communication, however, pertains more to Artificial Intelligence, and especially with methods that can handle naturally flowing information. Speech and writing recognition, in order to interface with any method of communication chosen by the citizen will be of paramount importance to bypass other, less natural input methods; linguistic register recognition, aiming at being able to interpret the non-verbal part of the discourse according to the tone and rhythm of conversation; ontology dynamical creation and update, in order to have a constant and accurate description of 'the world out there' that could be employed to direct information to the relevant parties; the informal use of formal structures (i.e. argumentation), at the aim of better understanding the kind of problems that elicit communication and to identify the actors that should play a role in the resulting conflict.

All of these tasks have in common that, as in any context where a natural language takes a predominant part, it is necessary to deal with incomplete, imprecise and missing information, uncertainty, heavy dependence from the context, an exact solution is not necessary or required (as sometimes it is even difficult to exactly pinpoint the originating problem). At the moment many of such kind of task are usually tackled by the use of a mix of brute force, statistical analysis and big data. While such approach has shown success in some research topics (speech recognition, personal digital assistants) and promising results in others (the first approaches to autonomous drive comes to mind), there are at least two obstacles to its widespread adoption. One of practical nature: some tasks, such as the understanding of the intricacies, anomalies and indeterminisms of human language, still seem out of reach such. The other, probably more important, goes at the nucleus of the problem. By using statistics and big data, introspection becomes difficult, if not impossible. And this fact is not a detail, as more often than not one of the principal reasons for AI application is not just the 'solution' of a problem by itself, but also a reflection on the way humans (and nature) tackle, solve and internalize problems. If we want to approach the problem of Citizen Communication toward a development of Cognitive Cities with the human factor in mind, we also have to look elsewhere: to Computational Intelligence.

Computational Intelligence (CI) is an umbrella term coined in the 00's to regroup all the methodologies and techniques that try to solve problems in contexts of ambiguous, incomplete, missing or vague information using approaches that are often derived from 'natural' methods, such as the ones devised by human minds or evolved in nature from animal behavior (Kacprzyk and Pedrycz 2015). In such context, algorithms derived from classical logic may be able to give an exact solution, but their requirements in time or space may be unfeasible for present and future technology, even more when the solution required has to be found in severe time constraint, such as in dynamically changing environments. CI methods are generally aimed at sub-optimal solutions that can nonetheless be achieved in a reasonable timeframe, and that are "good enough" for the intended problem (Seising 2010, 2012). A number of CI methods are directly inspired by human reasoning, especially among the earliest instances (such as Fuzzy Logic, Soft Computing and the likes), and as such are naturally matched with cognition and ideal to afford IA problems, insofar they distance themselves by grammars and inference rules.

3.2 Some Techniques

A number of articles in this book have been devoted by the authors to foundations of fuzziness, the founding father of CI (Seising and Tabacchi 2013; Termini and Tabacchi 2014; Tabacchi and Termini 2014). In this context, however, we deem appropriate to highlight some of the techniques that can be usefully applied to the problem of Citizen Communication for Cognitive Cities: Metaheuristics, Computing with Words, Computational Intelligence Classifiers, and Fuzzy-based Ontologies. The aim is not to give a detailed technical exposition of such methods, neither to review all the applicable technologies, but to give the reader the gist of the ways in which CI can be employed to implement Citizen Communication, and why this will be paramount for the functional development of Cognitive Cities thought by and for humans. Other techniques from Computational Intelligence may be usefully employed in designing Cognitive Cities (one glaring example is Fuzzy Cognitive Maps). In the rest of this volume some of such methods will be more thoroughly theoretically discussed and implemented.

3.2.1 Metaheuristics

Metaheuristics is an umbrella term designed to cover a group of 'smart' strategies to sub-optimally solve (within a certain, accepted degree of perfection) problems that are by their same nature intractable. This includes both general problems that are unsolvable due to their complexity increasing exponentially at the increase of the problem size (the so-called NP problems of the theory of computation), as well as optimization problems for which the difficulty lies in the inherent uncertainty, incomplete or imperfect information. Metaheuristics are based on the observation of ways in which nature (Evolutionary Computation, Ant colonies, Particle Swarms, and Genetic Algorithms) or humans (Simulated Annealing, Tabu Search, Local Search, Variable Neighborhood Search) solve in satisfactory ways problems that are apparently too complex to grasp, and are generally based on two assumptions: the first is that while a ‘perfect’ (in the computational, mathematical sense of the word) solution may not be attained, it is usually possible to find an alternative solution that satisfies the constraints put on the problem, and that is sufficiently similar, both in terms of time and space, to be acceptable. The second is that the usual way of solving a problem algorithmically—devise a number of steps that solve the problem, demonstrate the correctness, improve and repeat—can be replaced with a much more ecological procedure that explores the space of the problem in search of solution, often helped by the power of big data and high computational availability that characterizes today’s computing. This exploration is often helped by sampling subsets of the problem, the use of casual choices and continuous trial and error.

There is clearly a vast space for metaheuristics in designing cognitive cities: such methods echo the way humans reason, and by mimicking human and natural strategies in solving problems they both value practical requirements over theoretical aspects, as well as promoting exploration, multiple tries, trial and error, collaboration and cooperation, further refinements as means to succeed. Furthermore, the ample availability of computing power and of graphical tools that help both experts and novice to implement metaheuristics, as well as the innate nature of such techniques for being represented as visual abstractions, may represent a way of including in the design of cognitive cities also experts from the humanities, that are usually wary of classical computation techniques.

Metaheuristics have been recently used to improve urban transportation (Nha et al. 2012): a variation of the classical Travelling Salesman problem (finding shortest routes between a number of points in a city) is extended to a number of vehicles, and a dynamical situation where traffic conditions rapidly change. One advantage of metaheuristics is that by selectively choosen subsets of the problems they can make sense of big data, especially when dynamically captured through sensors, e.g. geographic information (Cosido et al. 2013). A review of methods from agent and multiagent systems, another offshoot of metaheuristics, shows that they have been applied to many aspects of traffic and transportation systems in dynamic changing environments (Chen and Cheng 2010), as well as planning the adoption of strategies to promote sustainability in cognitive cities (Juan et al. 2011).

3.2.2 Fuzzy Sets and Fuzzy Logic

The electrical engineer and professor at the University of California Berkeley Lotfi A. Zadeh (1921–2017) used to say, “Everything is a matter of degree!” (Fig. 3). This is the insight behind his introduction of the linguistic approach to fuzzy sets and systems, and, to appreciate it, we simply have to acknowledge that we name “everything” by words. In his editorial to the first issue of the International Journal of Fuzzy Sets and Systems, he wrote that “it has become increasingly clear” that “classical mathematics—based as it is on set theory and two-valued logic—is much too restrictive and much too rigid to serve as an effective tool for the understanding

Fig. 3 Lotfi A. Zadeh giving an interview in his office, Soda Hall, University of California at Berkeley, summer of 2012 (photocredit: Fuzzy archive Rudolf Seising)

of the behavior of humanistic systems, that is, systems in which human judgment, perceptions and emotions play an important role" (Zadeh 1978).

In order to provide a mathematically exact expression of experimental research with real systems, it was necessary to employ meticulous case differentiations, differentiated terminology and definitions that were adapted to the actual circumstances, things for which the language normally used in mathematics could not account. The circumstances observed in reality could no longer simply be described using the available mathematical means. Therefore, in the summer of 1964, Zadeh was thinking about pattern recognition problems and grades of membership of an object to be an element of a class as he returned to mind almost 50 years later (Zadeh 2011; Seising 2007). Zadeh submitted his seminal article "Fuzzy Sets" to the journal Information and Control and it appeared in June 1965 (Zadeh 1965).

He introduced new mathematical entities as classes or sets that "are not classes or sets in the usual sense of these terms, since they do not dichotomize all objects into those that belong to the class and those that do not" (Zadeh 1965). He introduced "the concept of a fuzzy set, that is a class in which there may be a continuous infinity of grades of membership, with the grade of membership of an object x in a fuzzy set A represented by a number $f_A(x)$ in the interval [0,1]." He generalized the concepts, union of sets, intersection of sets, etc. He defined equality, containment, complementation, intersection and union (Fig. 4) relating to fuzzy sets A, B in any universe of discourse X as follows (for all $x \in X$):

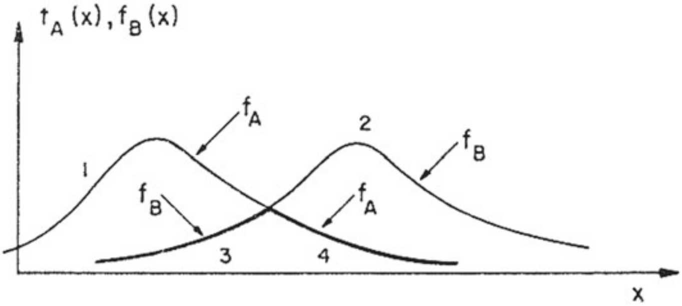

Fig. 4 Zadeh's Illustration of Fuzzy Sets in R^1: "The membership function of the union is comprised of curve segments 1 and 2; that of the intersection is comprised of segments 3 and 4 (heavy lines)" (Zadeh 1965)

- $A = B$ if and only if $\mu_A(x) = \mu_B(x)$,
- $A \subseteq B$ if and only if $\mu_A(x) \leq \mu_B(x)$,
- $\neg A$ is the complement of A, if and only if $\mu_{\neg A}(x) = 1 - \mu_A(x)$,
- $A \cup B$ if and only if $\mu_{A \cup B}(x) = \max\,(\mu_A(x), \mu_B(x))$,
- $A \cap B$ if and only if $\mu_{A \cap B}(x) = \min\,(\mu_A(x), \mu_B(x))$.

At Berkeley, Zadeh's efforts to use his fuzzy sets in linguistics led, in the early 1970s, to an interdisciplinary exchange between him and the linguist George Lakoff. The latter, referring to the accepted opinion "that sentences of natural languages (at least declarative sentences) are either true or false or, at worst, lack a truth value, or have a third value", argued "that natural language concepts have vague boundaries and fuzzy hedges and that, consequently, natural language sentences will very often be neither true, nor false, nor nonsensical, but rather true to a certain extent and false to a certain extent, true in certain respects and false in other respects" (Lakoff 1973). In this paper, Lakoff considered fuzzy sets appropriate for dealing with degrees of membership and with (concept) categories that have unsharp boundaries. Thus, Lakoff introduced the term "fuzzy logic".

Inspired and influenced by many discussions with Lakoff "concerning the meaning of hedges and their interpretation in terms of fuzzy sets", Zadeh contemplated "linguistic operators", which he called "hedges": "A basic idea suggested in this paper is that a linguistic hedge such as "very", "more", "more or less", "much", "essentially", "slightly" etc. may be viewed as an operator which acts on the fuzzy set representing the meaning of its operand."

However, based on his later research, Lakoff came to the conclusion that fuzzy logic is not an appropriate logic for linguistics: "It doesn't work for real natural languages; in traditional computer systems it works that way", he said years later. For Zadeh, fuzzy logic was the basis for "computing with words" instead of "computing with numbers" (Zadeh 1999). Later he said "the main contribution of fuzzy logic is a methodology for computing with words. No other methodology serves this purpose" (Zadeh 1996). For the new millennium, he proposed "A New Direction in AI. Toward