Interactive Granular Computing Connecting Abstract and Physical Worlds: An Example

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AGENDA

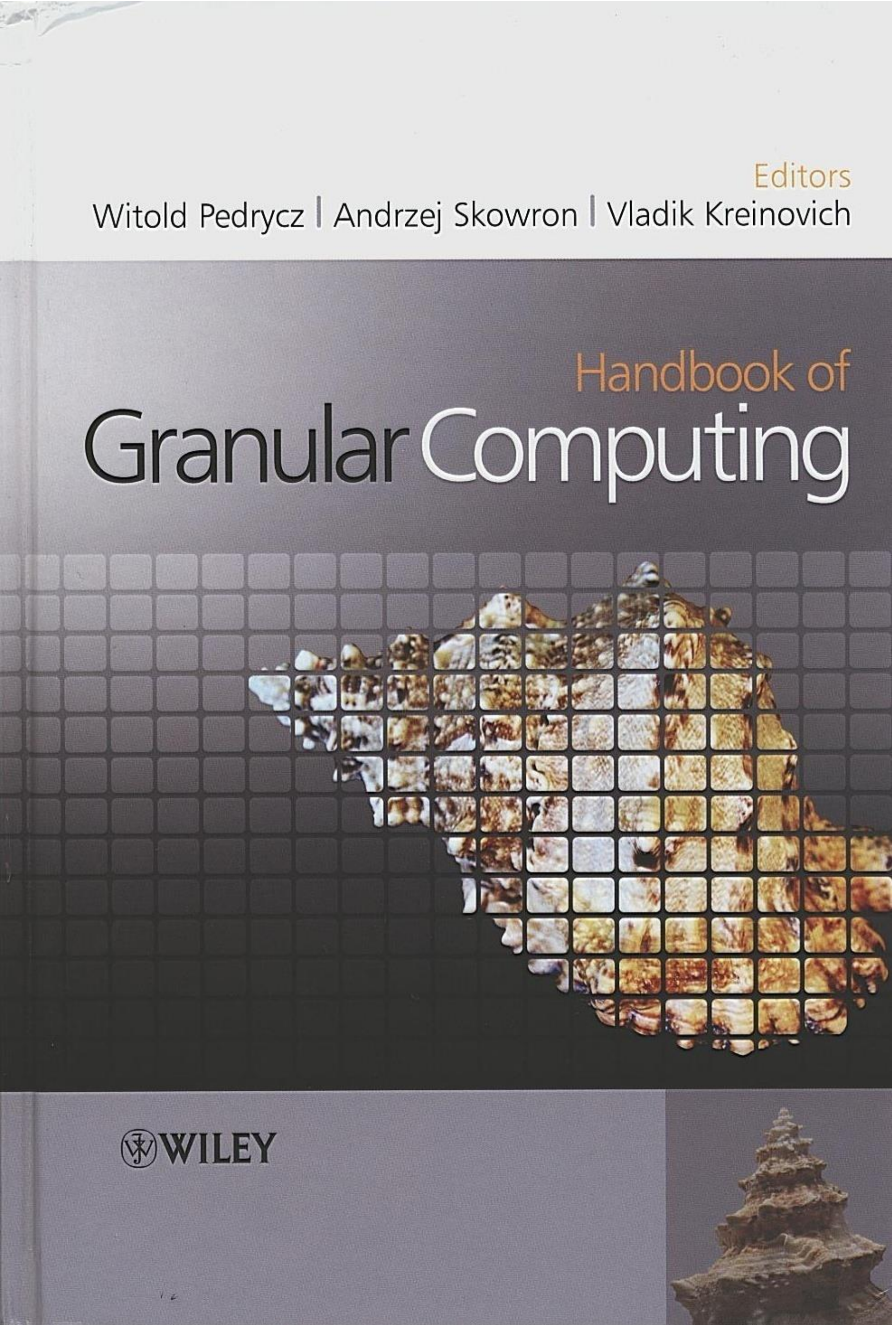
PART I

MOTIVATIONS FOR DEVELOPING NEW COMPUTING MODEL

SCIENCE, MANAGEMENT, LIFE,...

Tomorrow, I believe, we will use
DECISION SUPPORT SYSTEMS,
INTELLIGENT SYSTEMS
to support our decisions
in defining our research strategy and specific aims,
in managing our experiments,
in collecting our results, interpreting our data,
in incorporating the findings of others,
in disseminating our observations,
in extending (generalizing) our experimental observations
- through exploratory discovery and modeling -
in directions completely unanticipated

Bower, J.M., Bolouri, H. (Eds.): Computational Modeling of Genetic and Biochemical Networks. MIT Press, Cambridge, MA (2001)



Plays a key role in implementation of the strategy of divide-and-conquer in human problem-solving – Lotfi Zadeh

Zadeh, L. A. (1979) Fuzzy sets and information granularity. In: Gupta, M., Ragade, R., Yager, R. (eds.), Advances in Fuzzy Set Theory and Applications, Amsterdam: North-Holland Publishing Co., 3-18

Zadeh, L.A. (2001) A new direction in AI-toward a computational theory of perceptions. AI Magazine 22(1): 73-84

LESLIE VALIANT: TURING AWARD 2010

March 10, 2011:

Leslie Valiant, of Harvard University, has been named the winner of the 2010 Turing Award for his efforts to develop computational learning theory.

http://www.techeye.net/software/leslie-valiant-gets-turing-award#ixzz1HVBeZWQL

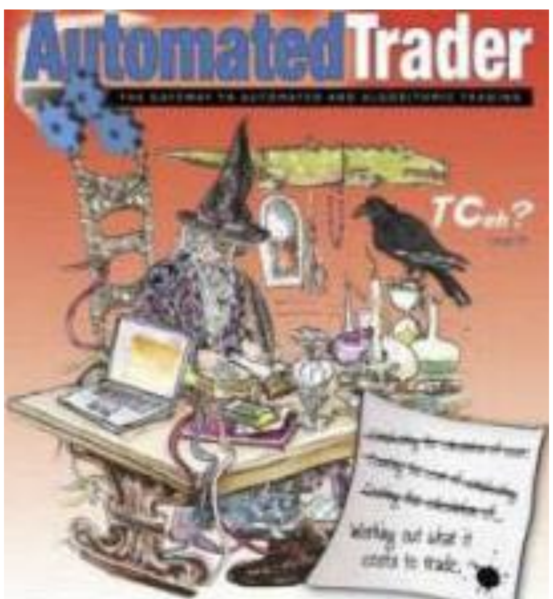
Current research of Professor Valiant

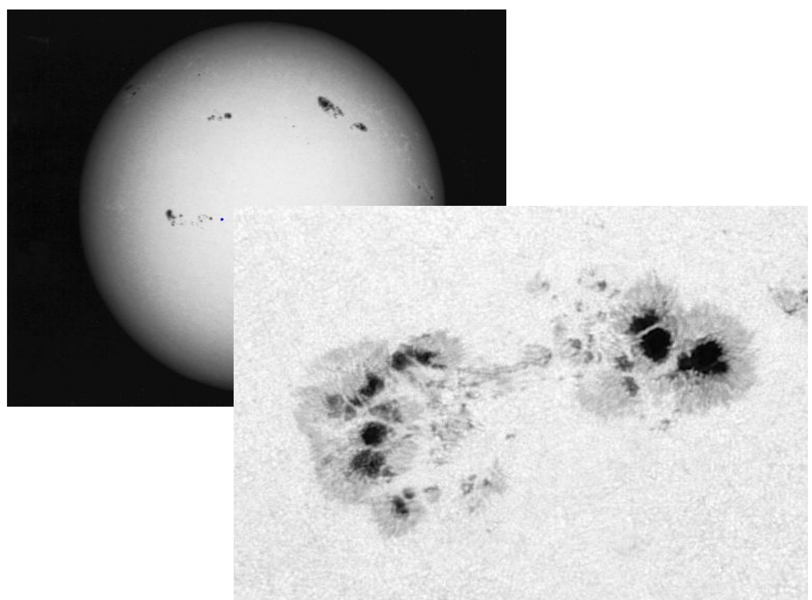
http://people.seas.harvard.edu/~valiant/researchinterests.htm

A fundamental question for artificial intelligence is to characterize the computational building blocks that are necessary for cognition.

INFORMATION GRANULES

APPLICATIONS :
APROXIMATION OF COMPLEX VAGUE CONCEPTS





WHAT NEXT?

ISSUES RELATED TO DATA SCIENCE:

BIG DATA GENERATED
BY
COMPLEX PHENOMENA
&
PERCEPTION AND ACTION

The main idea of this book is that perceiving is a way of acting. It is something we do. Think of a blind person tap-tapping his or her way around a cluttered space, perceiving that space by touch, not all at once, but through time, by skillful probing and movement. This is or ought to be, our paradigm of what perceiving is.

Alva Noë: Action in Perception, MIT Press 2004

PHENOMENOLOGY
originated by Edmund Husserl
as a method for exploring the nature of human experience and perception

Husserl was frustrated by the idea that science and mathematics were increasingly conducted on an abstract plane [treating nature itself as a mathematical manifold] that was disconnected from human experience and human understanding, independently of questions of truth and applicability. He felt that the sciences increasingly dealt with idealized entities and internal abstractions a world apart from the concrete phenomena of daily life.

Dourish, P.: Where the Action Is. The Foundations of Embodied Interaction. The MIT Press (2004)

BEYOND THE TURING TEST
&
JUDGMENT

The Turing test, as originally conceived, focused on language and reasoning; **problems of perception and action were conspicuously absent**. The proposed tests will provide an opportunity to bring four important areas of AI research (language, reasoning, perception, and action) back into sync after each has regrettably diverged into a fairly independent area of research.

C. L. Ortitz Jr. Why we need a physically embodied Turing test and what it might look like. AI Magazine 37 (2016) 55–62.

COMPLEX SYSTEMS

Complex system: the elements are difficult to separate. This difficulty arises from the interactions between elements. Without interactions, elements can be separated. But when interactions are relevant, elements co-determine their future states. Thus, the future state of an element cannot be determined in isolation, as it co-depends on the states of other elements, precisely of those interacting with it.

Gershenson, C., Heylighen, F.: How can we think the complex? In: Richardson, K. (Ed.): Managing Organizational Complexity: Philosophy, Theory and Application, pp. 47–61. Information Age Publishing (2005)

CHALLENGES

Mathematics and the physical sciences made great strides for three centuries by constructing simplified models of complex phenomena, deriving, properties from the models, and verifying those properties experimentally.

This worked because the complexities ignored in the models were not the essential properties of the phenomena. **It does not work when the complexities are the essence**.

Frederick Brooks: The Mythical Man-Month: Essays on Software Engineering. Addison-Wesley, Boston, 1975. (extended Anniversary Edition in 1995).

WHAT IS A COMPUTATION ?

Two main problems of Computer Science:

What is a state?
What is a transition relation?

What's an algorithm?
Yuri Gurevich
https://www.youtube.com/watch?v=FX2J24u92GI

WHAT IS A COMPUTATION ?

It seems that we have no choice but to recognize the dependence of our mathematical knowledge (...) on physics, and that being so, it is time to abandon the classical view of computations as purely logical notion independent of that of computation as a physical process.

David Deutsch, Artur Ekert,and Rossella Lupacchini,
Machines, logic and quantum physics.
Neural Computation 6 (2000) 265–283, p. 268

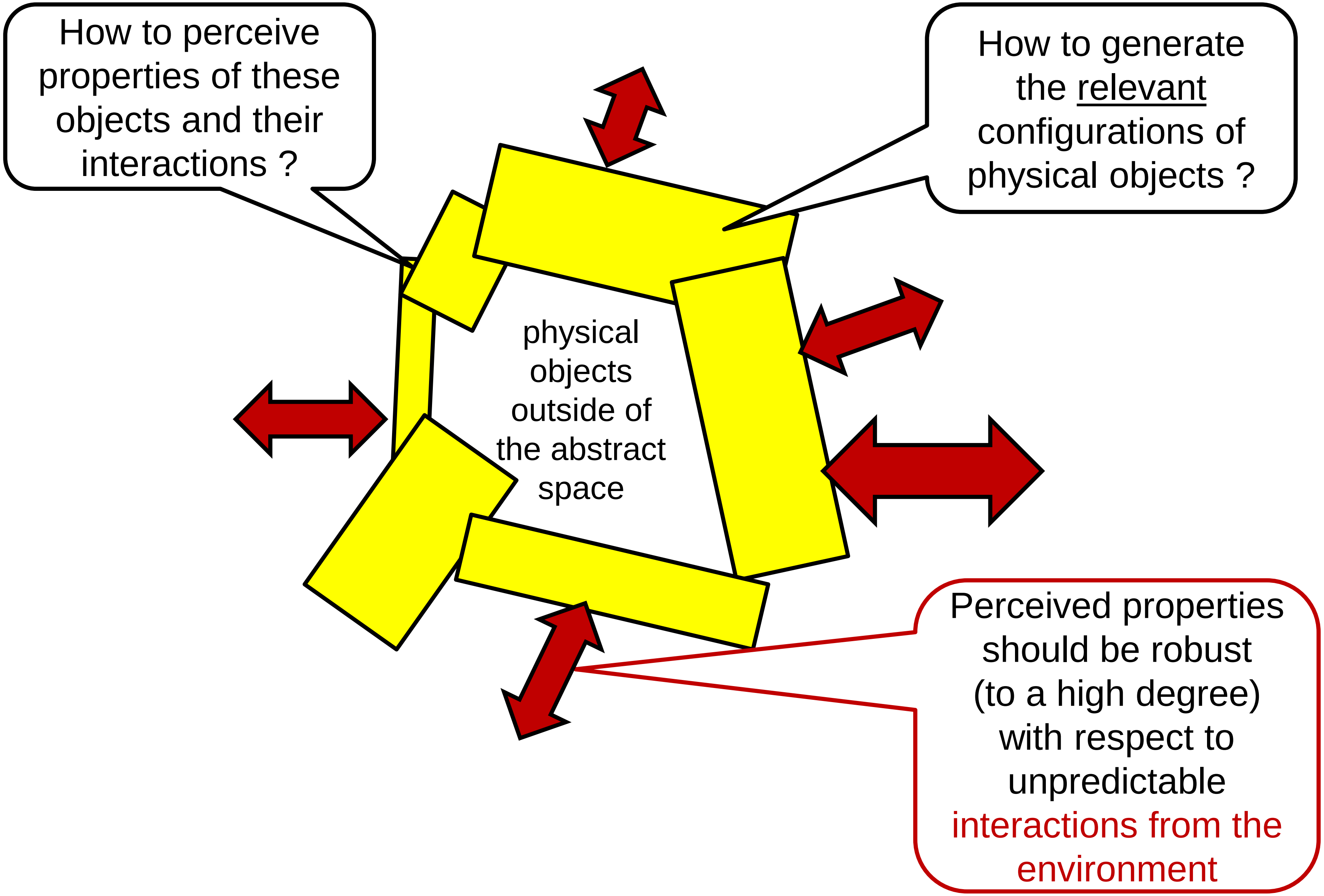
INTERACTIONS

[…] **interaction** is a critical issue in the understanding of complex systems of any sorts: as such, it has emerged in several well-established scientific areas other than computer science, like biology, physics, social and organizational sciences.

Andrea Omicini, Alessandro Ricci, and Mirko Viroli, The Multidisciplinary Patterns of Interaction from Sciences to Computer Science. In: D. Goldin, S. Smolka, P. Wagner (eds.): Interactive computation: The new paradigm, Springer 2006

INTERACTIVE GRANULAR COMPUTING (IGrC)

PROBLEM


How to perceive properties of these objects and their interactions ?
How to generate the relevant configurations of physical objects ?
physical objects outside of the abstract space
Perceived properties should be robust (to a high degree) with respect to unpredictable interactions from the environment

REASONING (JUDGMENT) REALISED IN IGrC SUPPORTING REALISATION OF PERCEPTION WITH GRANULATION INFORMATION IN INTELLIGENT SYSTEMS

AGENDA

PART II

LINKING IN IGrC TWO WORLDS
&
EXAMPLE

Soma Dutta

Agenda

- Proposing Interactive Granular Computing (IGrC) as a model where
  - Interactive symbolizes interaction between the abstract world and the real physical world, and
  - Granular Computing symbolizes computation over imperfect, partial, granulated information abstracted about the real physical world.
- Addressing the point that to build a model for complex systems it is not possible to
  - capture all complexities and dynamic changes of the system, happening due to the real physical interactions among the objects, by a static, pre-defined mathematical construct, and
  - ignore the method of cognizing or perceiving information about the objects

Why to develop a model connecting abstract and physical worlds

> *[...] cognition is the result of the interaction of two independent agents, the mind and the real object.*
>
> Immanuel Kant

From literature

> *The computational method of describing the ways information is processed is usually abstract but cognition is possible only when computation is realized physically, and the physical realization is not the same thing as its description.*
>
> *[...] we also need to account for how the computation is physically implemented.*
>
> *[...] we need to know how the computational mechanism is embedded in the environment, which, again, is not a purely computational matter.*

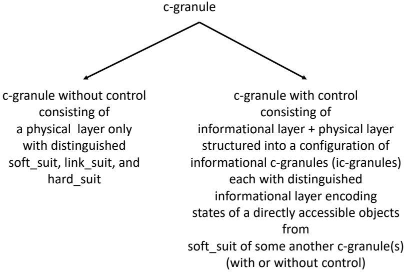
Miłkowski, M.: Explaining the Computational Mind. The MIT Press, Cambridge MA (2013)

Interactive Granular Computing: towards developing a model - not purely mathematical and isolated from real physical world

- What are the features that need to be added to develop such a model?
  - Learning the dynamics of the environemnt by perceiving real physical interactions
  - Connecting the abstract descriptions of the real physical environment, space-time locations, as well as the method of implementation of some actions on that environment with their respective real physical semantics, which may be partially perceived only
  - Ability to perceive the changes in the environment before, during, and after the interactions
  - Ability to reason, based on the current perception about the environment, what actions would be suitable and/or feasible

C-granule: Basis of Interactive Granular Computing (IGrC)

- C-granule is constructed over two sets of entities - a set of physical objects ($\mathcal{P}$) and a set of informational objects ($\mathcal{I}$).
- $\mathcal{I}$ consists of relevant information regarding the objects lying in $\mathcal{P}$ as well as relevant physical laws concerning the domain of $\mathcal{P}$.
- A c-granule can be with a control or without a control.



- Informally a control is a mechanism which can aggregate information about the objects from the scope of a c-granule and reason based on that.

C-granule (without control)

A c-granule (without control) is composed of three sets of physical objects from $\mathcal{P}$, known as soft_suit, link_suit and hard_suit. These three parts together determines the scope of the c-granule.

- Soft_suit: represents the objects from the physical reality which are directly accessible and/or about which already some information is encoded (by the control of some c-granule). Here by directly accessible we mean that by some already encoded knowledge, reasoning, and implementation mechanisms of the control of a given c-granule properties of those objects can be derived or obtained.
- Hard_suit: corresponds to those objects which are in the scope of the c-granule but not yet accessed or are not in the direct reach (of the control of some c-granule) at that point of time of the c-granule.
- Link_suit: represents a chain of objects that creates a communication channel between the soft_suit and the hard_suit.

In general, a c-granule without control is called as a c-granule.

Informational c-granule (ic-granule)

- A c-granule with control has the ability to store the relevant information about the perceived objects, and this information is attached to the c-granule as an information layer.
- A c-granule, when associated with an information layer with it, is known as informational c-granule, in short ic-granule.
- The information layer of an ic-granule contains different forms of information, such as
  - specification of the already perceived properties of the objects from its soft_suit,
  - specifications of the windows describing where and how some specific objects or fragments from the scope of the ic-granule can be accessed,
  - specifications of the already available knowledge and the respective memory locations,
  - specification of the local time etc.

Example: Considering lines from Nöe, A., Action in perception. MIT Press, Cambridge, MA (2004)

> *perceiving is a way of acting. [...] Think of a blind person tap-tapping his or her way around a cluttered space, perceiving that space by touch, not all at once, but through time, by skillful probing and movement. This is or ought to be, our paradigm of what perceiving is.*

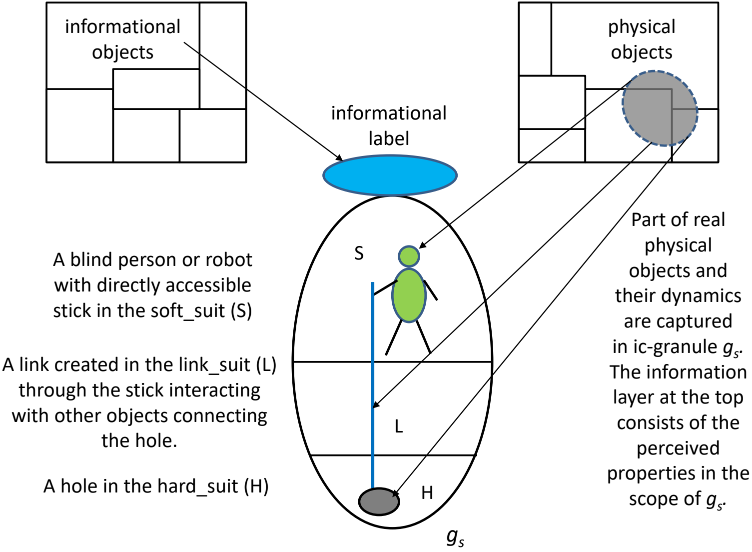
C-granule and ic-granule: from the example

Let $\mathcal{P}$ be a fragment of the physical world containing a blind person, a stick, and some surrounding objects from the environment. Let $\mathcal{I}$ contain the informational objects storing information relevant to the objects lying in $\mathcal{P}$.

- Let us consider g_{person} as a c-granule with control, which consists of the blind person, the stick, and some surrounding objects, holes from the environment. The soft_suit of g_{person} contains the person and the upper part of the stick, which is in direct touch of the person. The perceived properties of the objects lying in the soft_suit of g_{person} is attached to it as an information layer. So, g_{person} is an ic-granule.
- Let us consider g_{stick} as a c-granule without control, which consists of the stick and its surrounding from the physical environment. Some information about the stick may be already available in the information layer of g_{person}. But that information is not attached to g_{stick} as g_{stick} does not have a control with it. So, g_{stick} is a c-granule.

An exemplary ic-granule

A c-granule having in its scope a blind person and its surrounding.



Control of a c-granule

Control of a c-granule can also alternatively be named as control of a computation running over the c-granule.

- Control of a computation over a c-granule consists of all the information layers of the ic-granules lying in the scope, which may change with time, of the c-granule. All these information layers constitute the domain knowledge of the control.
- Moreover, control is also endowed with a reasoning mechanism which is responsible for aggregating, deleting, or generating the information from the existing clustered of information layers. Realisation of the reasoning mechanism of the control is reflected in the change of a configuration of ic-granules to another.
- Thus new configuration of ic-granules is generated applying the reasoning mechanism of the control on a given configuration of ic-granules.

Different types of ic-granule

Each c-granule with control can be regarded as a dynamic network of sub ic-granules. Based on the purposes and types of the information specifications of an ic-granule there can be different types of ic-granule.

- Perception based ic-granules: Information layers of such ic-granules contain specifications about the perceived properties of the objects lying in the soft_suits of the respective ic-granules.
- Knowledge based ic-granules: Information layers of such ic-granules contain specifications regarding general laws of the physical environment, specific properties of the concerned domain, laws of reasoning, as well as addresses where the knowledge of different domains are stored.
- Planner ic-granules: Information layers of such ic-granules specify the plans of actions to be implemented in order to reach a goal.
- Implementational ic-granules: Information layers of such ic-granules contain specifications, in a lower level or implementational level language, of how to implement a plan of actions. The information also specifies the expected properties of the concerned fragment of the physical environment after implementation of the actions.

Example: Sub ic-granules of g_{person}

- g_{kb} (the brain of the concerned person): The soft_suit of g_{kb} contains the directly accessible cells and memory location of the human brain; whereas the hard_suit contains more deeper analytical brain cells which needs to be activated by some interactions. The information layer of g_{kb} contains the addresses of the memory locations.
- g_{plan} (the analytical part of a human brain): In the context of our example, the soft_suit of g_{plan} contains those brain cells where the goal(s) of the person is registered. More analytical cells having the ability to decompose the goal(s) into further subtasks belong to the hard_suit of g_{plan}. The information layer of g_{plan} contains the goal description.
- Information layers of all these sub ic-granules can be accessed by the control of g_{person}. So, aggregating the information of the perceived environment (from the information layer of g_{person}), general physical laws (from the information layer of g_{kb}) and the goal specification (from the information layer of g_{plan}) a new configuration of ic-granules is created.

Computation over a c-granule

- A computation process running over a c-granule is represented by the evolutions of a finite sequence of configurations of ic-granules from a given configuration of ic-granules over time.
- A configuration of ic-granules comprises of some sub ic-granules of the concerned c-granule on which the computation is running.
- For example at the beginning point of time t_0 of a computation process the configuration of ic-granules consists of the perception based ic-granule g_s containing partial information about the perceived situation in the environment, knowledge based ic-granules g_{kb} containing relevant knowledge, and a planner ic-granule g_0 containing the description of the goal of the computation.
- Aggregating information layers of g_s, g_{kb} and g_0, at the next time point t_1, a new configuration of ic-granules may get evolved with more detailed plan of actions. That is, in the next configuration g_0 may change to a new planner ic-granule g_1. Moreover, there can be an implementational ic-granule g_i too representing the abstract plan of actions available at g_1 into a lower level language.

Example: Computation running over g_{person}

Layer-0: At t_0, the beginning of control's cycle

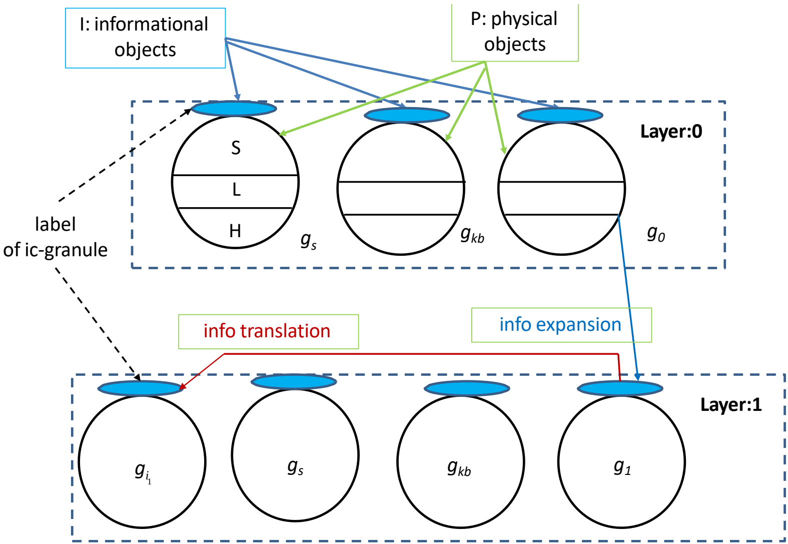
- g_{person} is labelled with the perceived information of the directly accessible objects from its soft_suit.
- Let the description of the general goal of the computation is attached as the information layer of a planner ic-granule g_{plan0}. Here the soft_suit, link_suit and the hard_suit can be like different layers of the brain cells where the reachability to more deeper layer in the hard_suit happens through the directly reachable layer in the soft_suit and reactions of the brain cells propagating from the soft_suit to the hard_suit.
- g_{kb} can be considered as the brain cells related to the memory locations. The information layer of g_{kb} is labelled with the addresses of different relevant properties of different fragments of g_{person}.
- Using the information from the information layers of g_{person}, g_{plan0} and g_{kb}, the control decomposes a detailed plan of actions, which is labelled at the ic-granule g_{plan1} at the next time point t_1.

Layer-1

- At t_0 the information attached to g_{plan0} encodes the general goal of the blind person; the hard_suit of g_{plan0}, such as deeper analytical brain cells, remains still unaccessed. At time t_1 the person ponders more analytically; this in a sense activates interaction with the previously unaccessed part of g_{plan0}. This gradually gives access to the hard_suit of g_0, and thus at time t_1 the hard_suit of g_{plan0} becomes the soft_suit of g_{plan1}, labelled with a more detailed plan for the person.
- To implement the abstract description of the plan available at g_{plan1} through a real physical action, the plan needs to be transformed from the abstract level to an implementational level language, which can be a translation of the plan from the person's analytical brain cells to a language of actuators, like hands, legs, and the stick of the person. So, a new ic-granule is manifested at this layer. We call it as g_{i_1}, an implementational ic-granule.

To be noted that g_{i_1} does not concern about the actual actuators; rather it is like another hard-drive in the brain of the person where the action plan can be stored in the language of actuators.

Computation running from layer-0 to layer-1



Layer-2

- The specification of the plan of implementation of g_{i_1} is now realized through a physical object at time t_2. Let this object belong to the scope of the ic-granule g_2. Here g_2 can be the same as g_{person} and the object can be the stick of the blind person on which the abstract implementation plan is embedded. The expected properties of the physical interactions of the stick with other objects in g_{person} is encoded in the information layer of g_{person}.
- With the action compilation the objects lying in its link_suit and hard_suit propagate actions to realize a desired configuration in the hard_suit of g_{person}. This new interaction gives access to the hard_suit of g_{person} which was previously unaccessible.

Beyond pure mathematical formulation

- In IGrC computation process deals with a set of hunks of real physical matter associated with their information layers; the information layers indicates where, when and how they can be touched, or their properties can be achieved or verified.
- The implementational ic-granules create a specific interface between the abstract and the physical world by launching actions. These actions, realized by the implimentational ic-granules, are not from abstract mathematical space and the model of IGrC keep those action functions free from mathematical formalizations. Their syntactic descriptions can be formalised in the informational layers of the control of the c-granule. However, their implementation should be realised in the real physical world and the model only can mathematically formalize their expected performance quality and adapt the behaviour of the control by perceiving the changes in the world after initiation of the actions.

Incorporates the presence of real physical actions, without trying to formalize it by a static mathematical notion

- Let us illustrate the idea of decomposition of the description of the action plan in order to transform an ic-granule with a given property, say α, into another one with the property β.
- After several levels of decomposition it reaches a level at which the relevant actions are launched by the control so that the expected realisation of the whole chain of actions can lead to a situation satisfying, to a satisfactory degree, the property β.
- Though the conditions of the chain of actions and the expected properties after the actions are specified by α's and β's, the actual actions $ac_1, \ldots ac_k$ are not in in the realm of mathematical formulation.
- In IGrC the results of actions are perceived by recording the properties of the resultant configurations. Then the recorded properties are verified with the expected property β. Control of c-granule must be equipped with strategies of adaptation of the behaviour according to the perceived differences between expected properties and real perceived properties.

Beyond pure mathematical formulation

Transformation specification *tr* from an ic-granule with property α to an ic-granule with property β available at the planner ic-granule g_0

$$\alpha : g_0 \Rightarrow_{tr} \beta : g$$

$$\propto: g_o \Rightarrow_{tr_1} \alpha_1: g_1 \quad \alpha_1: g_1 \Rightarrow_{tr_2} \beta: g$$

...

$$\propto: g_o \Rightarrow_{tr_1} \alpha_1: g_1 \quad \dots \quad \alpha_{k-1}: g_{k-1} \Rightarrow_{tr_k} \beta: g$$

plan : ac_1 ... ac_k

IGrC: In future advances of information technology

Tomorrow, I believe, we will use DECISION SUPPORT SYSTEMS, INTELLIGENT SYSTEMS to support our decisions in defining our research strategy and specific aims, in managing our experiments, in collecting our results, interpreting our data, in incorporating the findings of others, in disseminating our observations, in extending (generalizing) our experimental observations - through exploratory discovery and modeling - in directions completely unanticipated.

Bower, J.M., Bolouri, H. (Eds.): Computational Modeling of Genetic and Biochemical Networks. MIT Press, Cambridge, MA (2001)

Spliting into different research directions: a few

- New model for intelligent systems: Present needs of Intelligent Systems (IS) are not met by using only static knowledge; it demands the ability of dynamically learning new information and updating reasoning strategies based on interactions with the real physical environment as IS often deal with complex phenomena of the physical world.
- New model for complex systems:

> *Complex system: the elements are difficult to separate. This difficulty arises from the interactions between elements. Without interactions, elements can be separated. But when interactions are relevant, elements co-determine their future states. Thus, the future state of an element cannot be determined in isolation, as it co-depends on the states of other elements, precisely of those interacting with it.*

Gershenson, C. and Heylighen, F.: How can we think the complex? In: K. Richardson, (Ed.): Managing Organizational Complexity: Philosophy, Theory and Application. Information Age Publishing, pp. 47-61 (2005).

Contd. . .

- New model for understanding state and transition relation: In usual context, for a given family of sets $\{X_i\}_{i \in I}$ by a transition relation we mean a relation $tr_i \subseteq X_i \times X_i$. In the present context, we need to incorporate the components which can specify (i) how elements of X_i are perceived in the real physical environment, and (ii) how the transition relation tr_i is implemented in the real physical world.
- New model for information/decision systems: Decisions based on the information about a set of objects with respect to a fixed set of attributes is not enough. An intelligent system should know where and how those information is collected; if it requires a method of perceiving then it should know how that method can be implemented, and if it requires a method of reasoning, it should be able to choose either of abductive, deductive, and inductive strategies based on requirements. So, the notion of information system should incorporate a notion of window specification describing the way for perceiving data as well as the possibility of continuous interactions with the environment in order to check if the syntactic window specification of data collection matching with the real physical configuration.

THANK YOU