INTERACTIVE GRANULAR COMPUTING: TOWARD COMPUTING MODEL FOR COMPLEX INTELLIGENT SYSTEMS

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AGENDA

Motivations for

- development of computing model creating the basis for the design and analysis of Complex Intelligent Systems (IS's), i.e., Intelligent Systems dealing with complex phenomena

Interactive Granular Computing (IGrC)

- Complex granules (c-granules)
  - Specification (syntax)
  - Physical semantics of specification
    - States and dynamics
- Perception of situations in the physical world by c-granules with control (or societies of such c-granules)
  - Structure of c-granules: from elementary to networks; IS's – examples of c-granules with control
  - Control as a sub-granule of a given granule with control
  - Modeling of perception by control: generation and management (steering) of configurations of sub-granules
  - Granular computations generated by c-granules with control
- Challenge for control of a given c-granule (IS): The discovery of adaptive complex games that aim to generate high quality, approximate solutions to problems along granular computations that are steered by the control of c-granule.

Summary

MOTIVATIONS FOR NEW COMPUTING MODEL

THE RELEVANT COMPUTING MODEL: FOUNDATIONS FOR DESIGN AND ANALYSIS OF IS’s

Many partial proposals in many different domains exist,
e.g., multi-agent systems, machine learning, robotics, cognitive science, neuroscience, computational intelligence, natural computing, …

but we need
the relevant computing model for developing foundations of IS’s.

WE PROPOSE IGrC AS SUCH A MODEL

DEALING WITH COMPLEX PHENOMENA

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).

BEYOND THE TURING TEST
&
REASONING

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.

PHYSICAL SEMANTICS

Constructing the **physical part of the [learning] theory** and unifying it
with the mathematical part should be considered
as one of
the main goals of statistical learning theory

Vladimir Vapnik, Statistical Learning Theory, Wiley 1998,
(Epilogue: Inference from sparse data, p. 721)

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 (2011)
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 computation as a 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)

GRANULES & PERCEPTION

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.

COMPLEX GRANULES

GRANULAR COMPUTING (GrC):

GRANULES CLOSED
IN THE ABSTRACT SPACE ONLY

INTERACTIVE GRANULAR COMPUTING (IGrC):

GRANULES
IN THE ABSTRACT AND PHYSICAL SPACES
FOR PRCEPTION MODELING

FROM GrC TO IGrC

GrC, with abstract information granules as basic objects, is generalized to IGrC through the introduction of complex granules (c-granules), which are the fundamental objects of IGrC. These combine abstract and physical objects, enabling the perception of their properties through the control of c-granules. The IGrC model differs from the classical Turing model. In the IGrC model, both language and reasoning issues as well as actions and perception are significant. Research on IGrC utilizes existing partial results from various fields, such as multi-agent systems, perception and action, machine learning, natural language processing, and more.

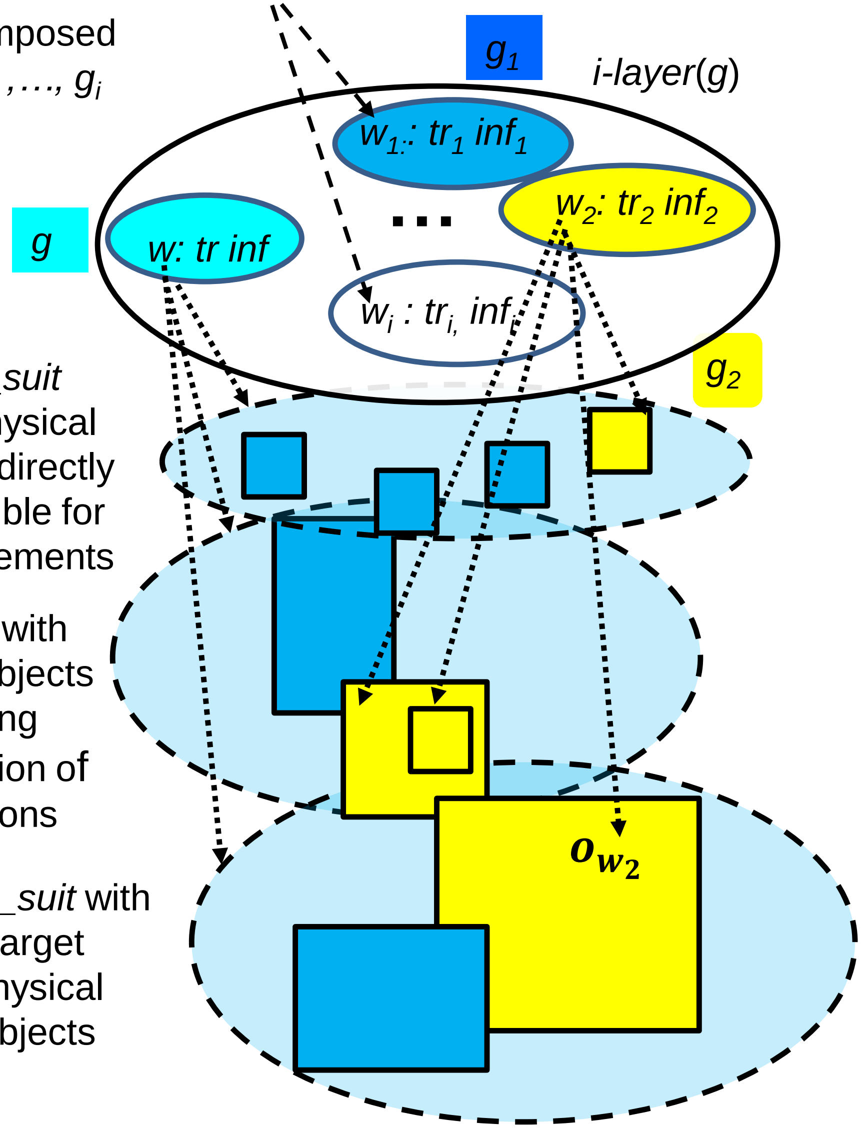
C-GRANULES
FROM ELEMENTARY TO NETWORKS AND SOCIETIES OF C-GRANULES: EXAMPLES

C-GRANULE: INTUITION

specifications of (families of) spatio-temporal windows realized by control as physical pointers to the corresponding parts of the physical space

w – scope of granule *g* composed out of family of granules $g_1, \ldots, g_i$

||*w*|| - realization of *w* with the family of physical objects in *p-layer*(*g*)



soft_suit with physical objects directly accessible for measurements

link_suit with physical objects providing transmission of interactions

hard_suit with target physical objects

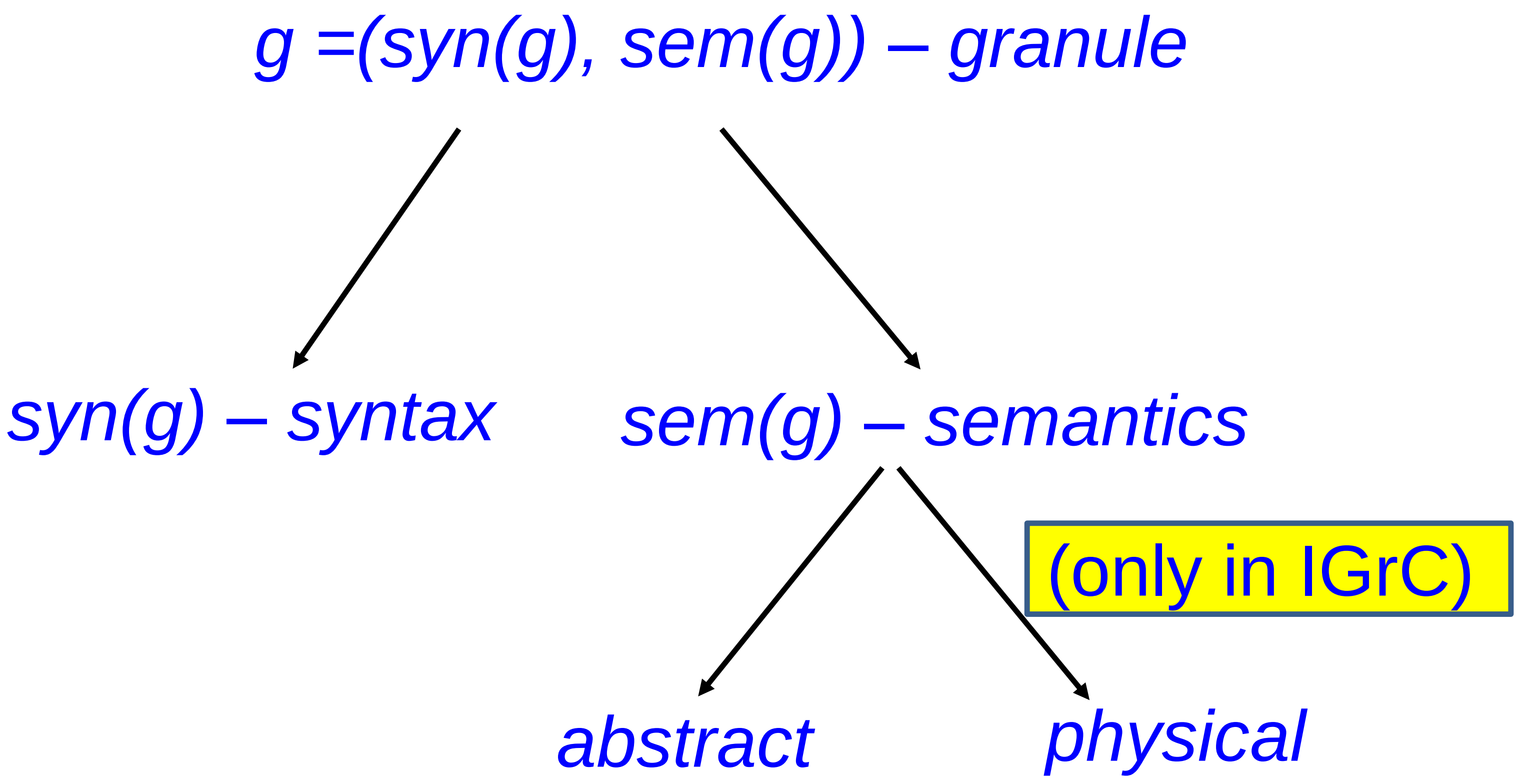
p-layer(*g*)

see: signals in the book by Holland

State of c-granule is changing with local time of c-granule; dynamics dependent on interactions of physical and abstract objects

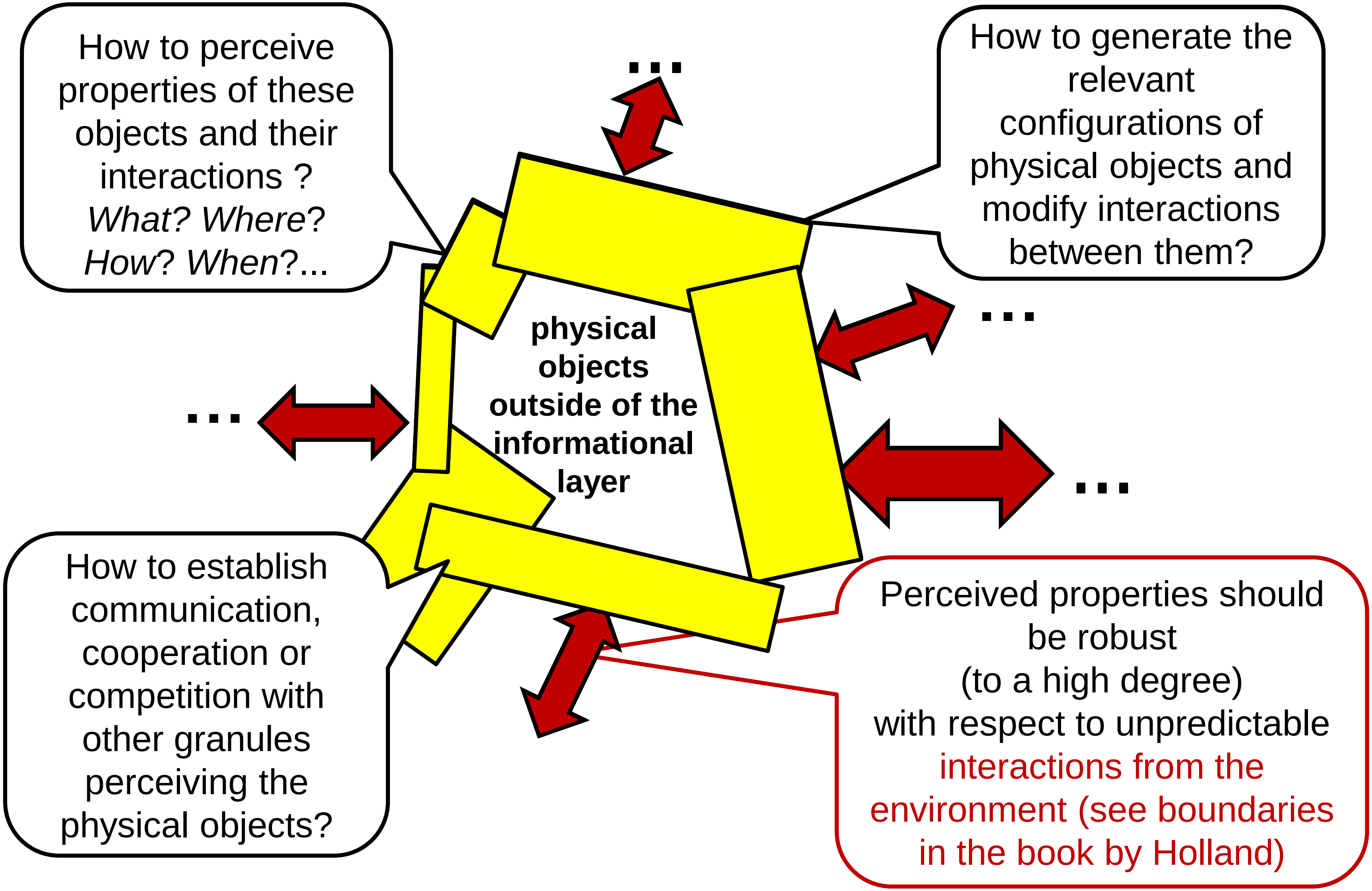
properties of physical objects from *hard_suit*, *link_suit* and their interactions encoded in inf_i are based on already perceived properties, granule structure, physical laws and/or knowledge bases

GRANULAR COMPUTING (GrC)
and
INTERACTIVE GRANULAR COMPUTING (IGrC)



Physical semantics is realized by implementational module (IM) -- a sub-granule of c-granule control.

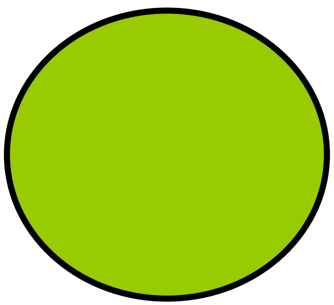
HOW C-GRANULES ARE GENERATED, MODIFIED AND MANAGED?

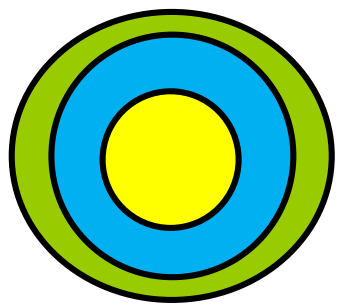


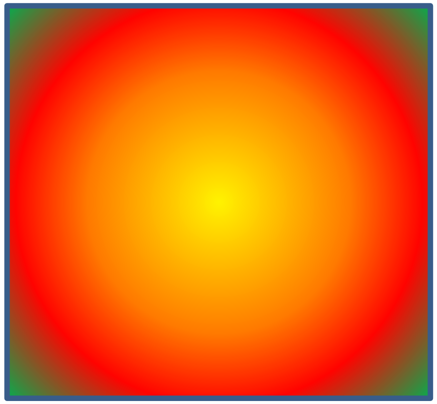
EXAMPLES OF C-GRANULES

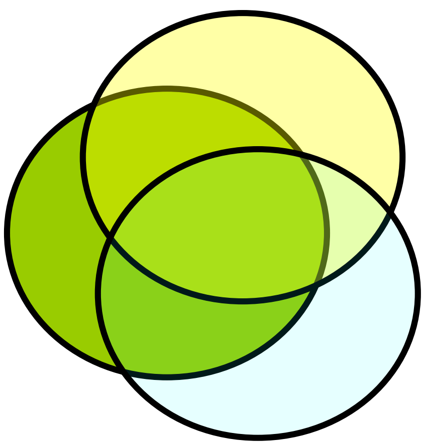
CALCULI OF GRANULES
=
ELEMENTARY (INFORMATION OR/AND COMPLEX) GRANULES
+
OPERATIONS ON GRANULES

Examples of families of elementary granules









…

g =(syn(g), sem(g)) – granule

syn(g) – syntax of g expressed in a language L

sem(g) – semantics of g: crisp (or fuzzy) set of objects (already defined granules)

ELEMENTARY ABSTRACT GRANULES FROM INFORMATION SYSTEMS

	a_1	a_2	...	a_m
x_1	v_1	v_2	...	v_m
	...	...	...	...

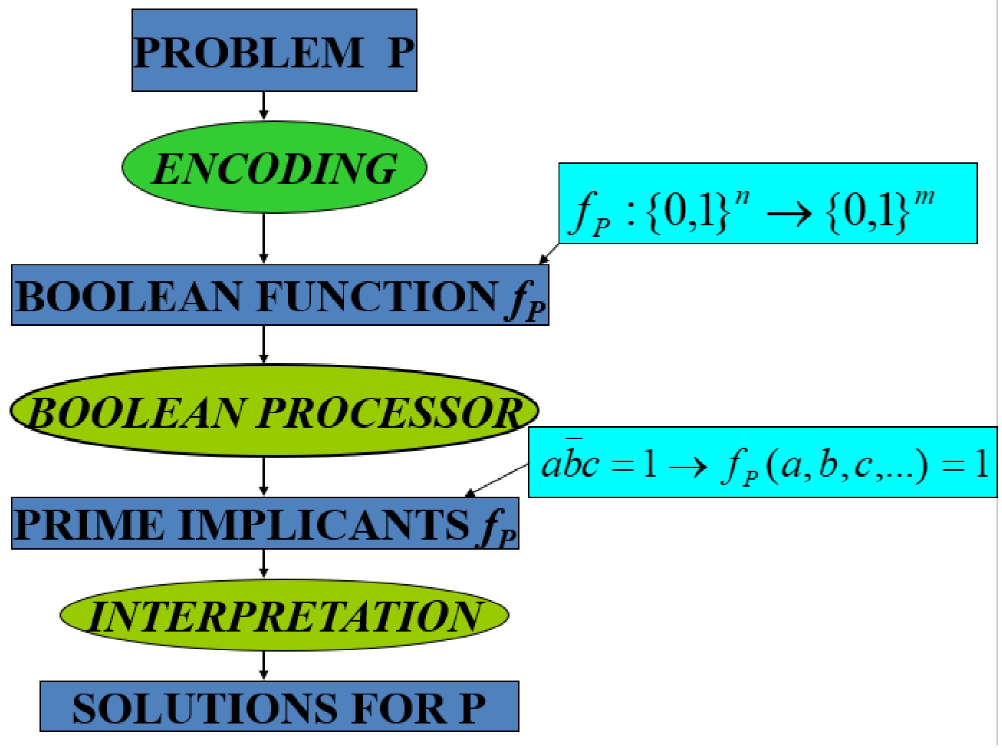
- indiscernibility classes of (subsets of) attributes
- partitions defined by attributes
- partitions defined by subsets of attributes
- granules defined by calculi over the above granules
- …

OPTIMIZATION PROBLEMS

- feature selection
- data reduction
- discretization
- symbolic value grouping
- decision rules
- …

BOOLEAN REASONING

George Boole (1815-1864)



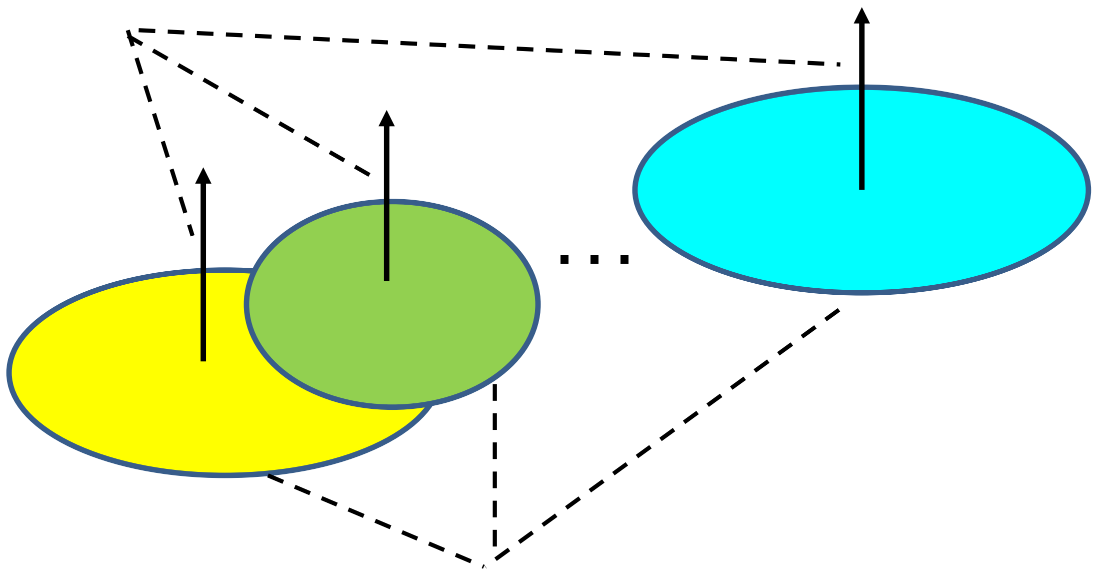
ELEMENTARY GRANULES LINKING ABSTRACT AND PHYSICAL OBJECTS

- **encoding information from information granules into physical objects**
- **decoding results of sensory measurements and actions from physical objects into information granules**

COMPLEX GAMES

DISCOVERY
OF COMPLEX GAMES AND THEIR EVOLUTION
IN THE CONTEXT OF
INTERACTING
ABSTRACT AND THE PHYSICAL WORLDS

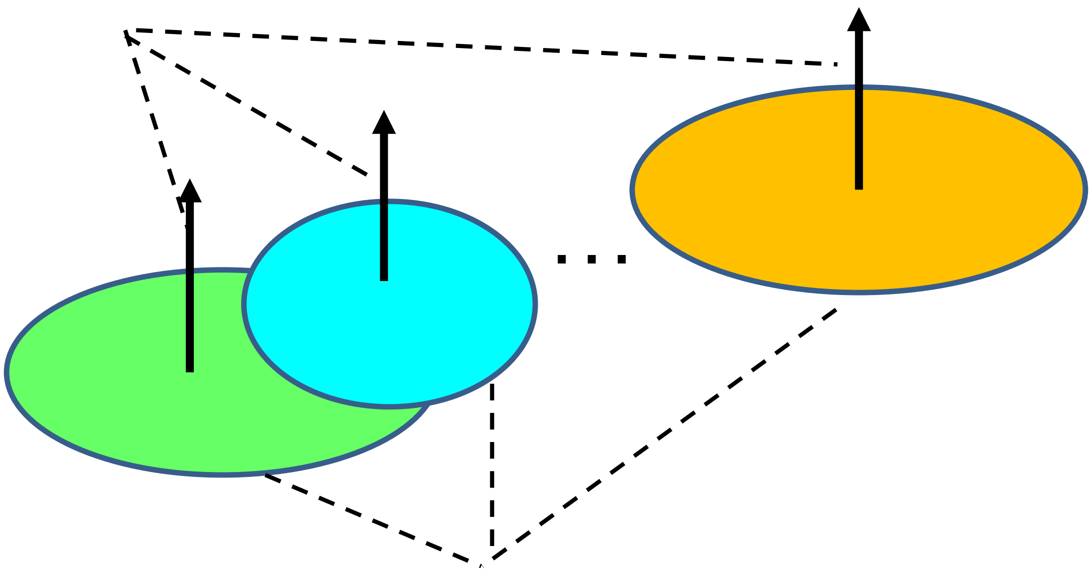
actions/plans aiming to perform the relevant measurements/ actions
toward achieving the target goals



complex vague concepts
triggering actions/plans

DISCOVERY
OF COMPLEX ADAPTIVE GAMES
IN THE CONTEXT OF
INTERACTING
ABSTRACT AND THE PHYSICAL WORLDS

complex games for situations with the relevant properties



complex vague concepts
triggering complex games

GRANULAR NETWORKS
AS OBJECTS ON WHICH GRANULAR COMPUTATIONS IN IGrC ARE REALIZED:

EXAMPLES

GRANULAR NETWORKS LINKED BY INTERFACES

GN_1 granular network

- elementary (atomic) granules
- transformations for constructing granules
- methods (algorithms) for generation new granules, modifying existing ones and reasoning about computations over them
- …

Interface

$Inter(GN_1, GN_2)$

- Relations between granules from GN_1 and GN_2
- Transformations of granules from GN_1 to GN_2
- Rules for reasoning about properties of granules from GN_2 on the basis of properties of granules from GN_1 transformed to granules from GN_2
- Methods for generation of new samples of granules in GN_1 and GN_2
- …

GN_2 ranular network

- elementary (atomic) granules
- transformations for constructing granules
- methods (algorithms) for generation new granules, modifying existing ones and reasoning about computations over them
- …

NETWORK OF APPROXIMATION SPACES LINKED BY INTERFACES FOR THE PAWLAK ROUGH SET MODEL

$G_R = \{g_x : x \in U\}$

$R \subseteq U \times U$ – *equivalence relation*

$g_x = (f([x]_R), [x]_R)$, $x \in U$

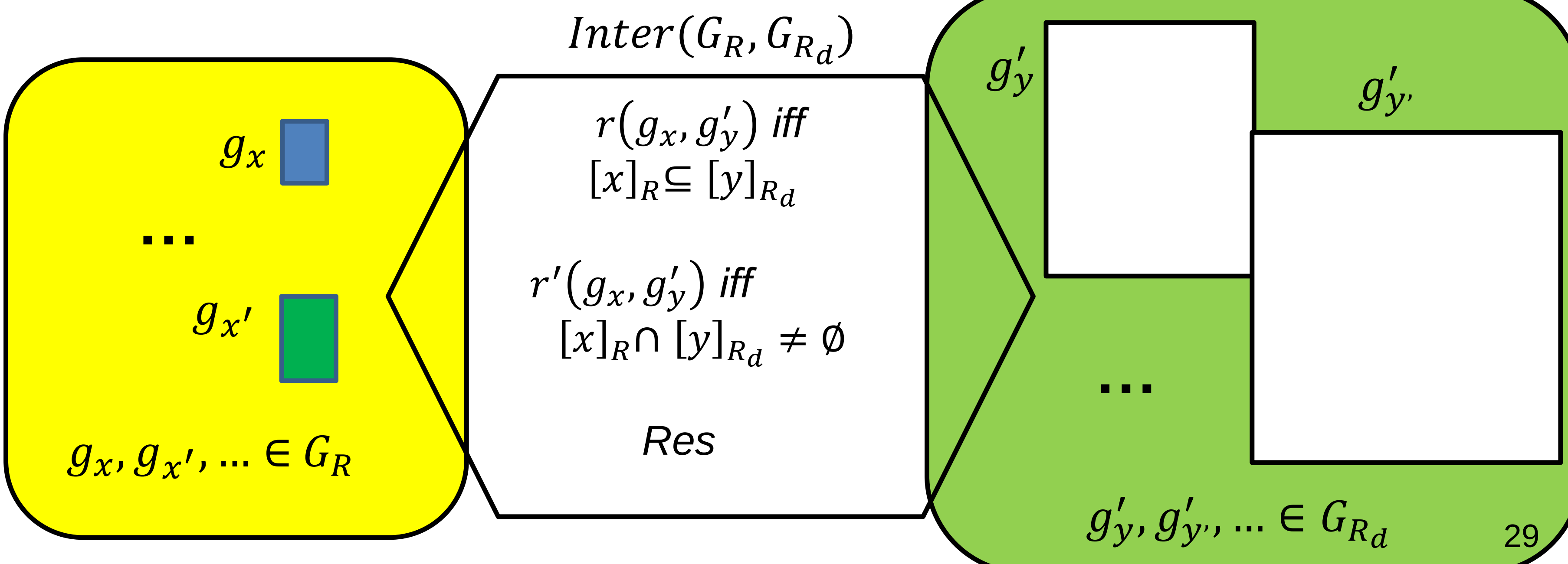
$f: U/R \rightarrow \{1, \dots, |U/R|\}$ - *bijection*

$G_{R_d} = \{g'_y : y \in U\}$

$R_d \subseteq U \times U$ – *equivalence relation*

$g'_y = (h([y]_{R_d}), [y]_{R_d})$, $y \in U$

$h: U/R_d \rightarrow \{1, \dots, \lceil U/R_d \rceil\}$ - *bijection*



NETWORK OF APPROXIMATION SPACES INDUCED FROM THE NETWORK OF APPROXIMATION SPACES FOR PAWLAK'S ROUGH SET MODEL: EXAMPLE

$R^* \subseteq U^* \times U^*, U \subseteq U^*, R = R^* \cap (U \times U), G_{R^*} = \{g_x^*: x \in U^*\}$

$g_x^* = (f^*([x]_{R^*}), [x]_{R^*}),\ x \in U^*$

$f^*: U^*/R^* \to \{1, \ldots, |U^*/R^*|\}$- *bijection,*

$f^*([x]_{R^*}) = f([x]_R)$ *for* $x \in U$

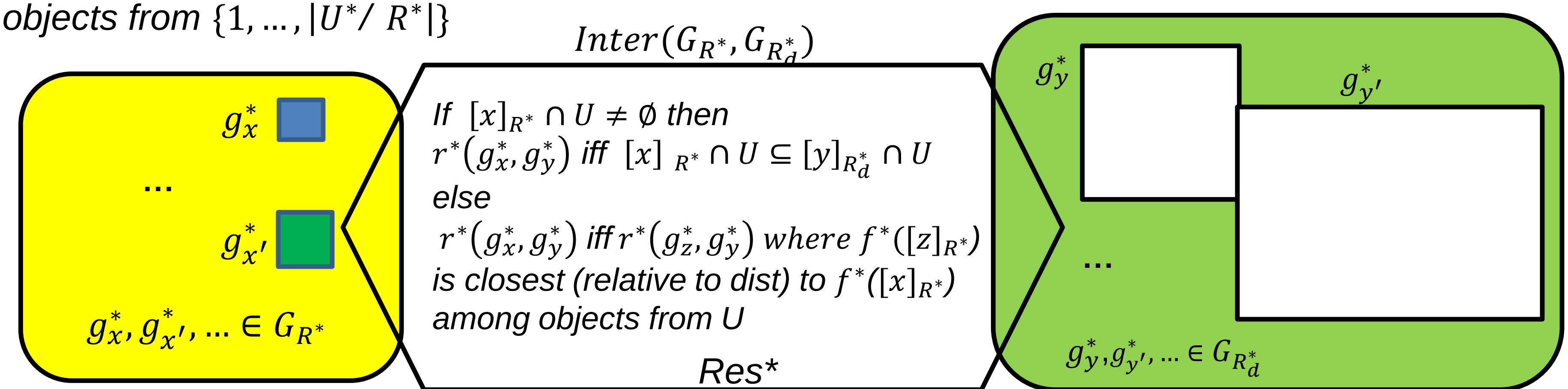
dist – distance function between objects from $\{1, \ldots, |U^*/R^*|\}$

$R_d^* \subseteq U^* \times U^* \quad G_{R_d^*} = \{g_y^*: y \in U^*\}$

$g_y^* = (h([y]_{R_d^*}), [y]_{R_d^*}),\ y \in U^*$

$h^*: U^*/R_d^* \to \{1, \ldots, [U^*/R_d^*]\}$ *– bijection,*

$h^*([x]_{R^*}) = h([x]_R)$ *for* $x \in U$



inductve extension

$R \subseteq U \times U,\ G_R = \{g_x: x \in U\}$

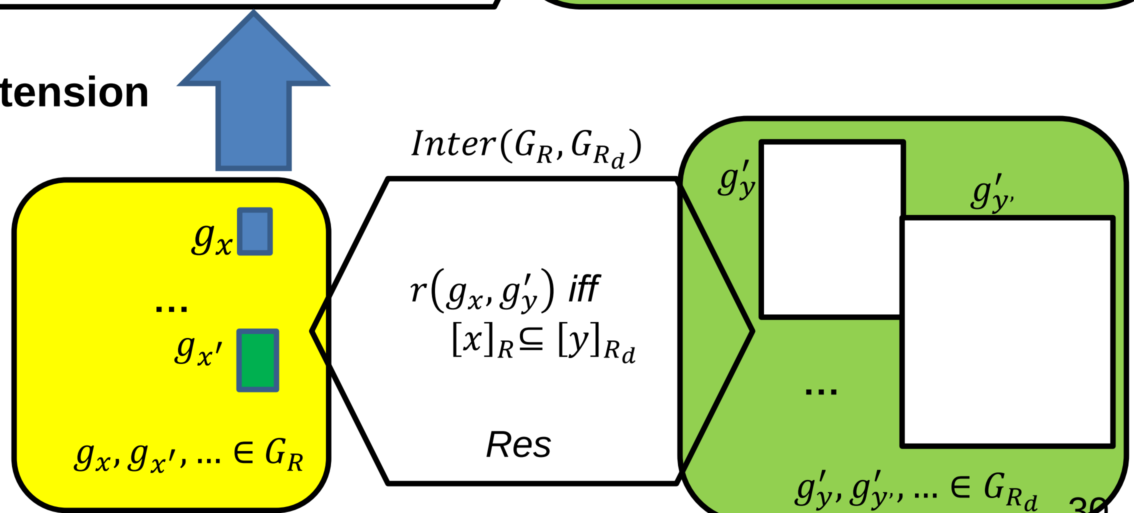
$g_x = (f([x]_R), [x]_R),\ x \in U$

$f: U/R \to \{1, \ldots, |U/R|\}$ *- bijection*

$R_d \subseteq U \times U, G_{R_d} = \{g'_y: y \in U\}$

$g'_y = (h([y]_{R_d}), [y]_{R_d}),\ y \in U$

$h: U/R_d \to \{1, \ldots, [U/R_d]\}$ *- bijection*

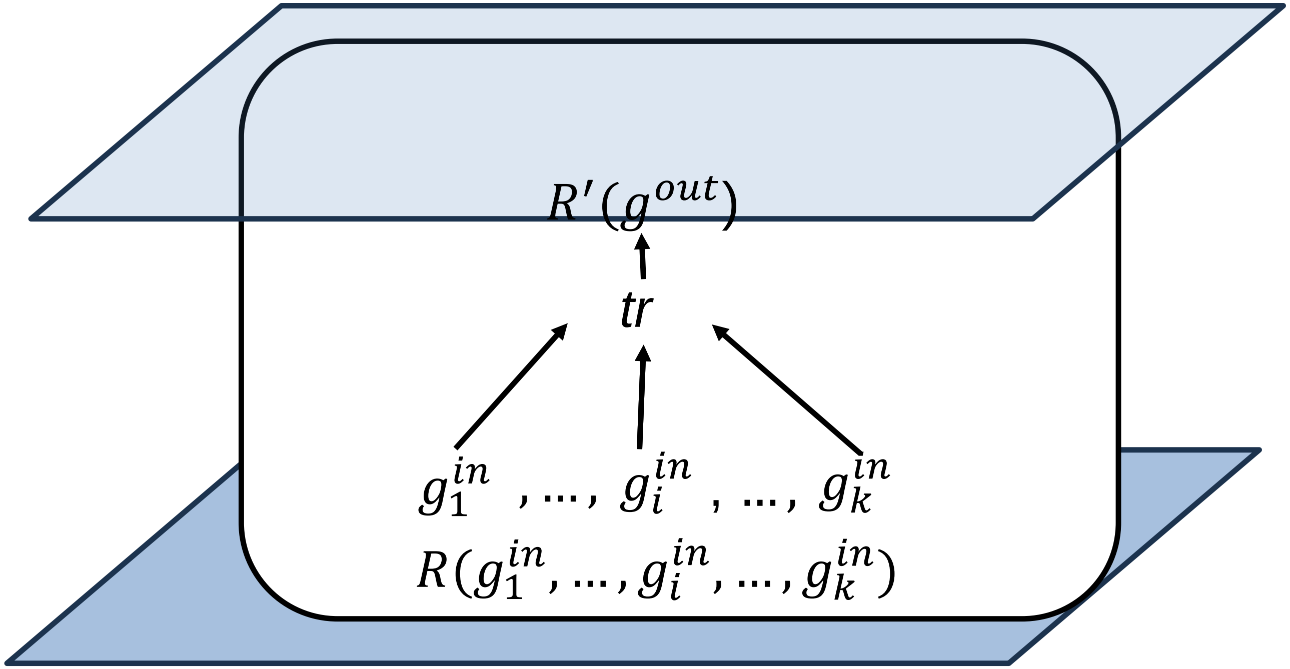


SIMPLIFIED NETWORK OF APPROXIMATION SPACES FOR PAWLAK'S ROUGH SET MODEL

INTERFACES BETWEEN GRANULAR NETWORKS OVER DIFFERENT UNIVERSES

- generation of new types of granules from given ones

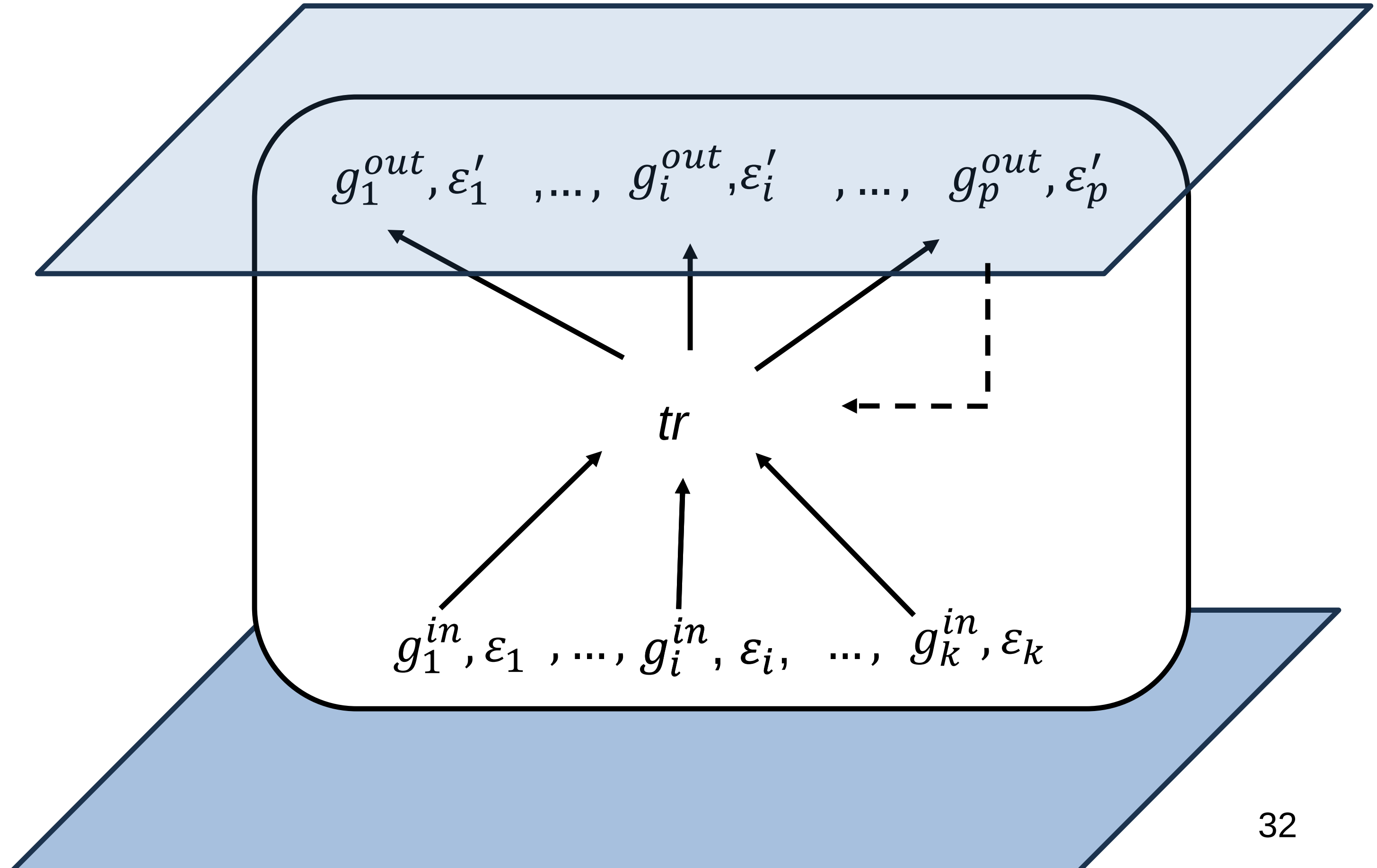
g^{out} g_i^{in} *tr*
-- often represented by relevant algorithms



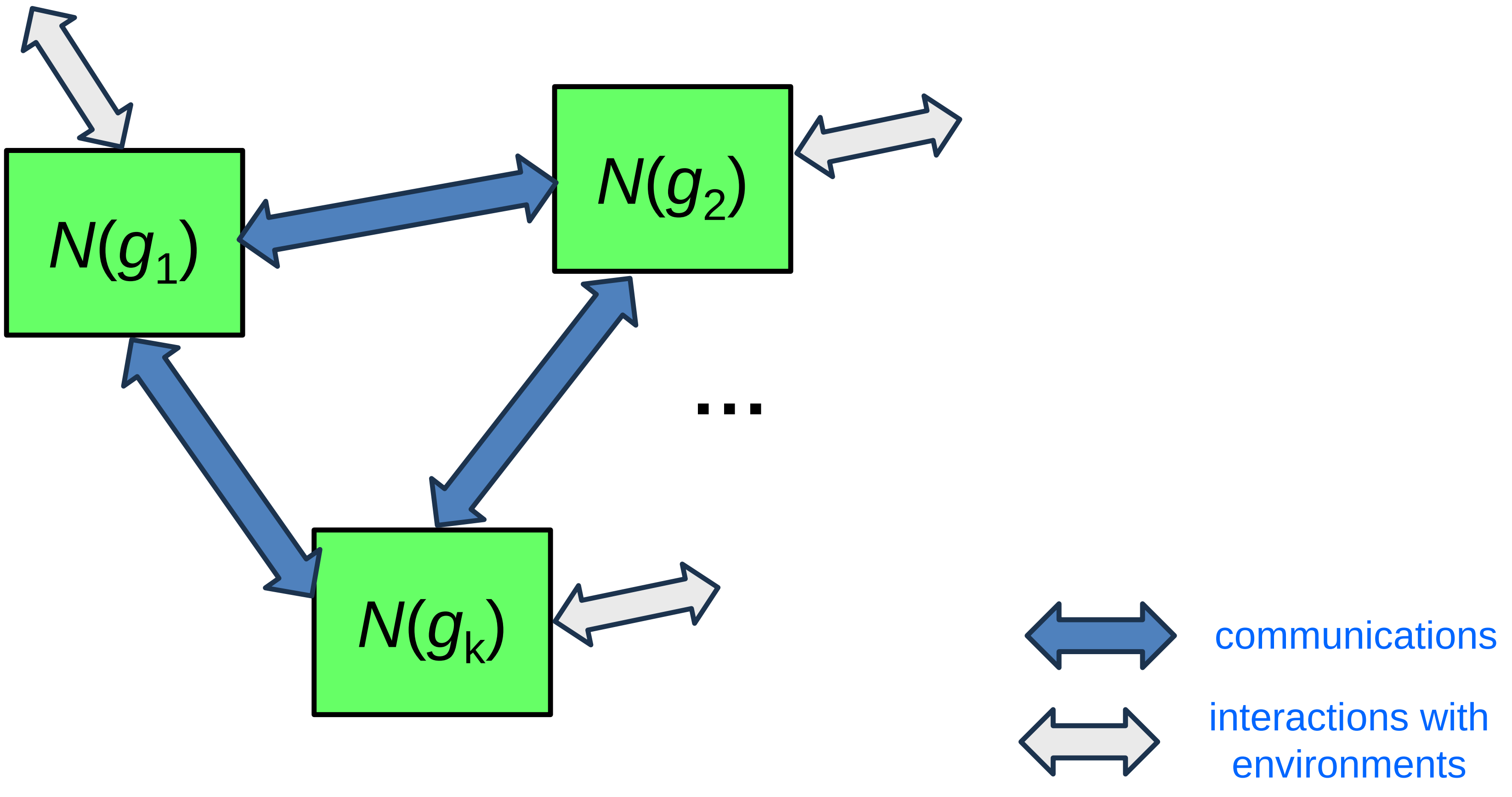
Example: *tr* - learning algorithm constructing an ensemble of classifiers from given classifiers; *R*' - the quality of constructed classifier; *R* – constraints on aggregated of classifiers (e.g., they are generated from a given decision system). Optimization: searching for $g_1^{in}, \ldots, g_i^{in}, \ldots, g_k^{in}$ and their aggregations for obtaining g^{out} with the required quality measured by R'.

INTERFACES BETWEEN GRAULAR NETWORKS WITH RULES CONCERNING ROBUSTNESS

g_i^{out} g_i^{in} *tr*
can be often represented by relevant algorithms



GRANULAR SOCIETIES

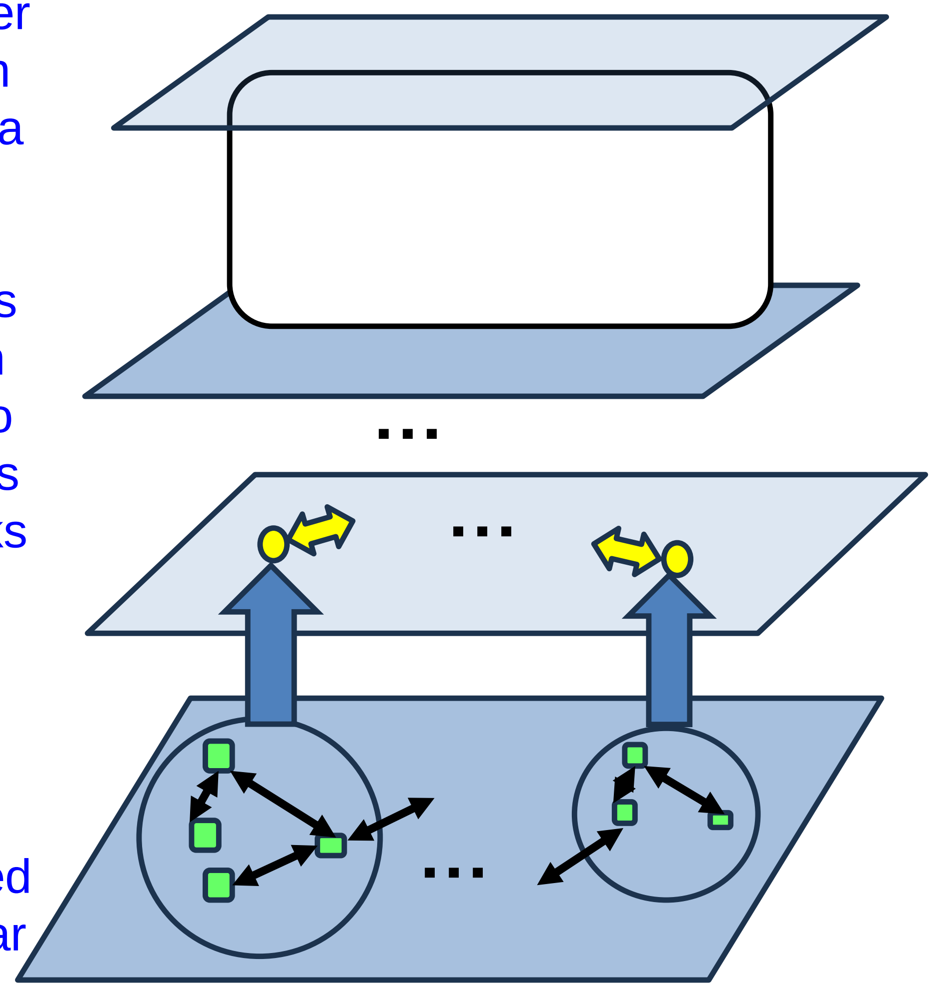


The $N(g_1)$, $N(g_2)$, …, $N(g_k)$ are granular networks for the granules g_1, g_2, …, g_k, and arrows represent the interactions between them that realize communication in the form of cooperation or competition.

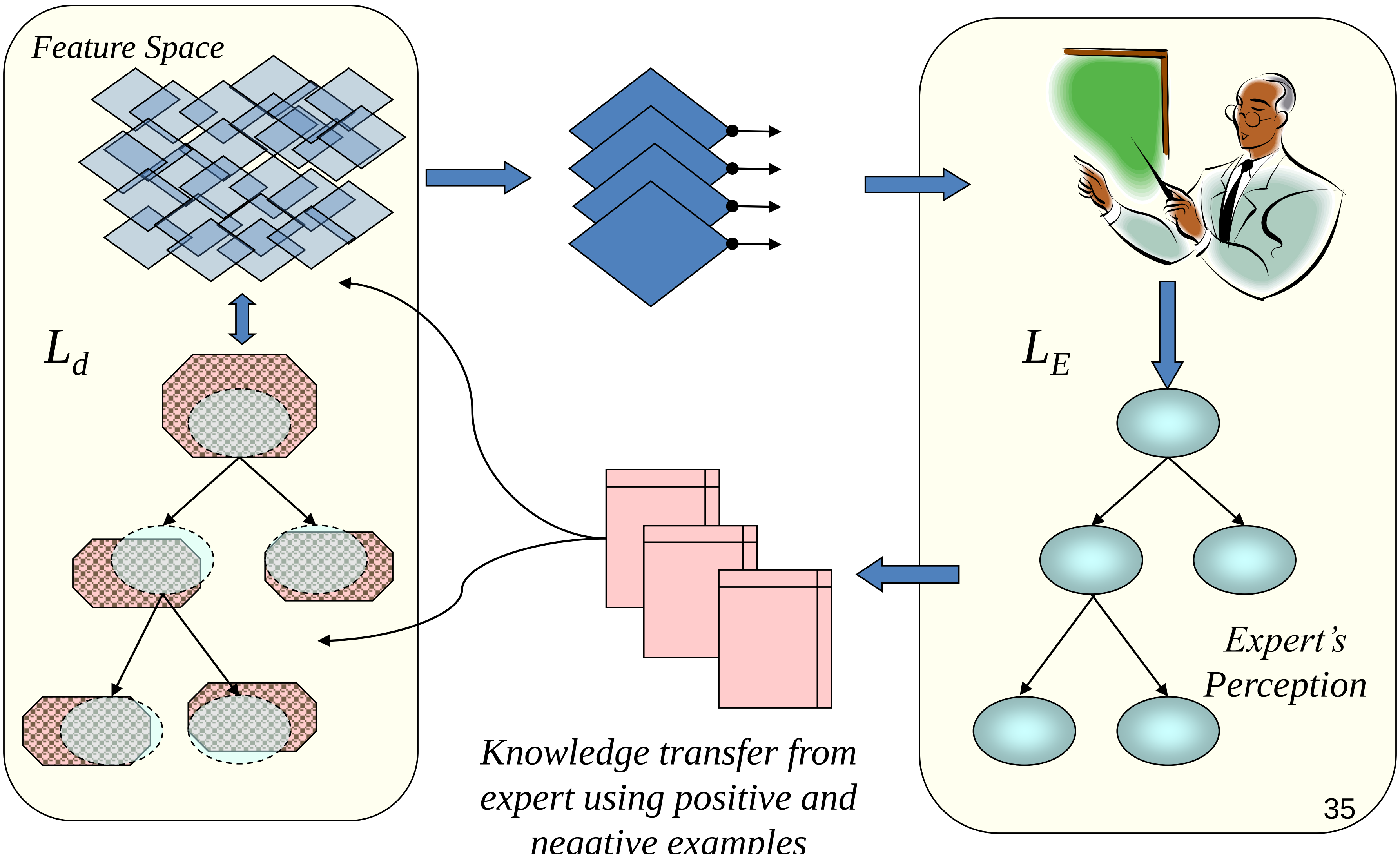
HIERARCHIES OF GRANULAR NETWORKS OF GRANULAR SOCIETIES

complex dynamic granules

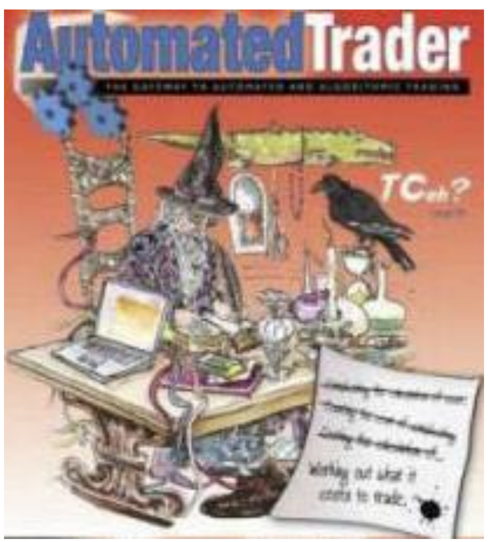
The aim of granulation of granular (sub)societies into hierarchies is to discover computational building blocks for cognition of situations related to complex phenomena in physical spaces. This process involves identifying behavioral models of granular societies within more complex societies, as well as the relationships between them. In particular, it reveals rules that allow one to infer the properties of higher-level networks based on collections of lower-level networks that satisfy certain constraints. These constraints may be determined, e.g., by membranes or by interactions between collections of granules (see Holland's book).(See Holland's book.)
The hierarchical approach may be also used for reasoning about the behavior of granular society on the lowest level of hierarchy.

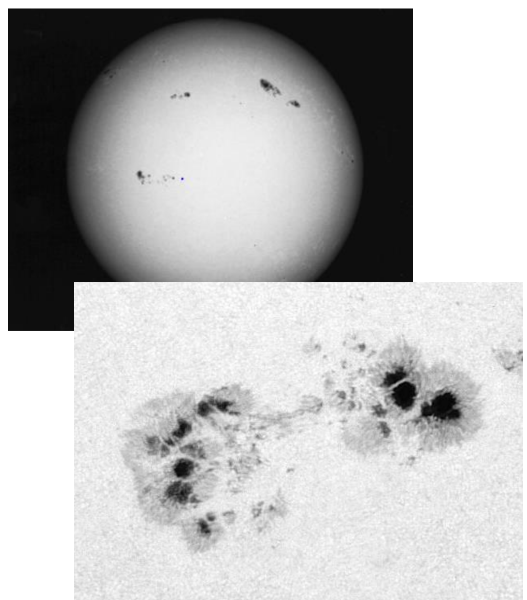


ROUGH SET BASED ONTOLOGY APPROXIMATION



APPLICATIONS :
APROXIMATION OF COMPLEX VAGUE CONCEPTS





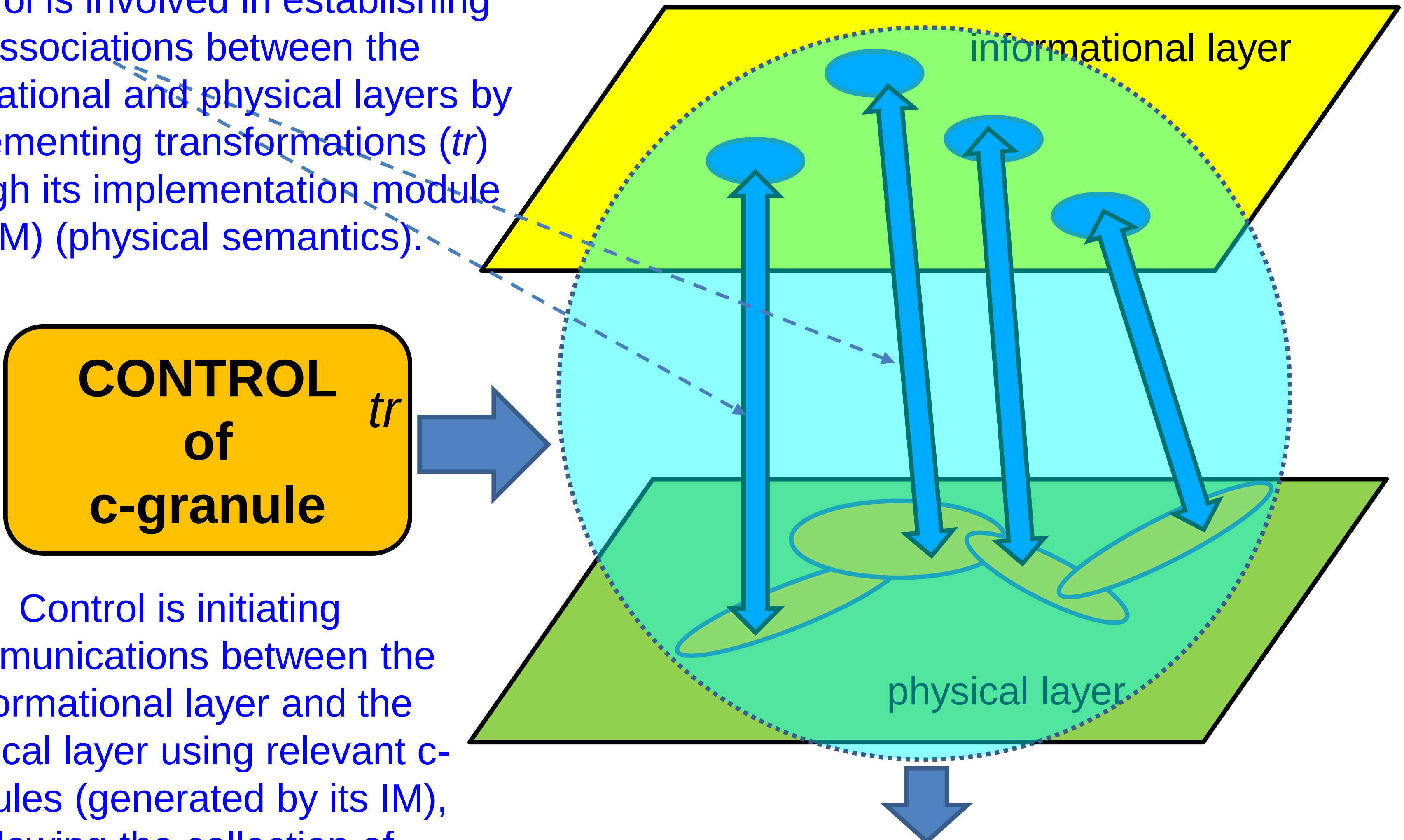
CONTROL OF C-GRANULE *g*
(a sub-granule of *g*)
IS AIMING TO STEER GENERATED GRANULAR COMPUTATIONS IN ORDER TO ENSURE THE ACHIEVEMENT OF ITS GOALS TO A SATISFACTORY DEGREE

C-GRANULE WITH CONTROL: INTUITION

Control of c-granules implements processes aimed at understanding perceived situations in order to construct approximate solutions to problems "along" the generated granular computations. This is achieved by discovering complex games. Each complex game consists of a set of rules. The predecessor in each such rule is a classifier for often complex, vague concepts that activate the rule. If the rule is selected by the control for implementation, a realization is triggered in the physical world based on the transformation specification on the right side of the rule, applied to the current granular network. The implementation module (IM) of c-granule control is responsible for the physical realization of the transformation specification (i.e., for the physical semantics). It may be necessary to conduct a multi-level decomposition of the transformation specification intended for implementation before it can be directly realized in the physical world.

C-GRANULE WITH CONTROL: INTUITION

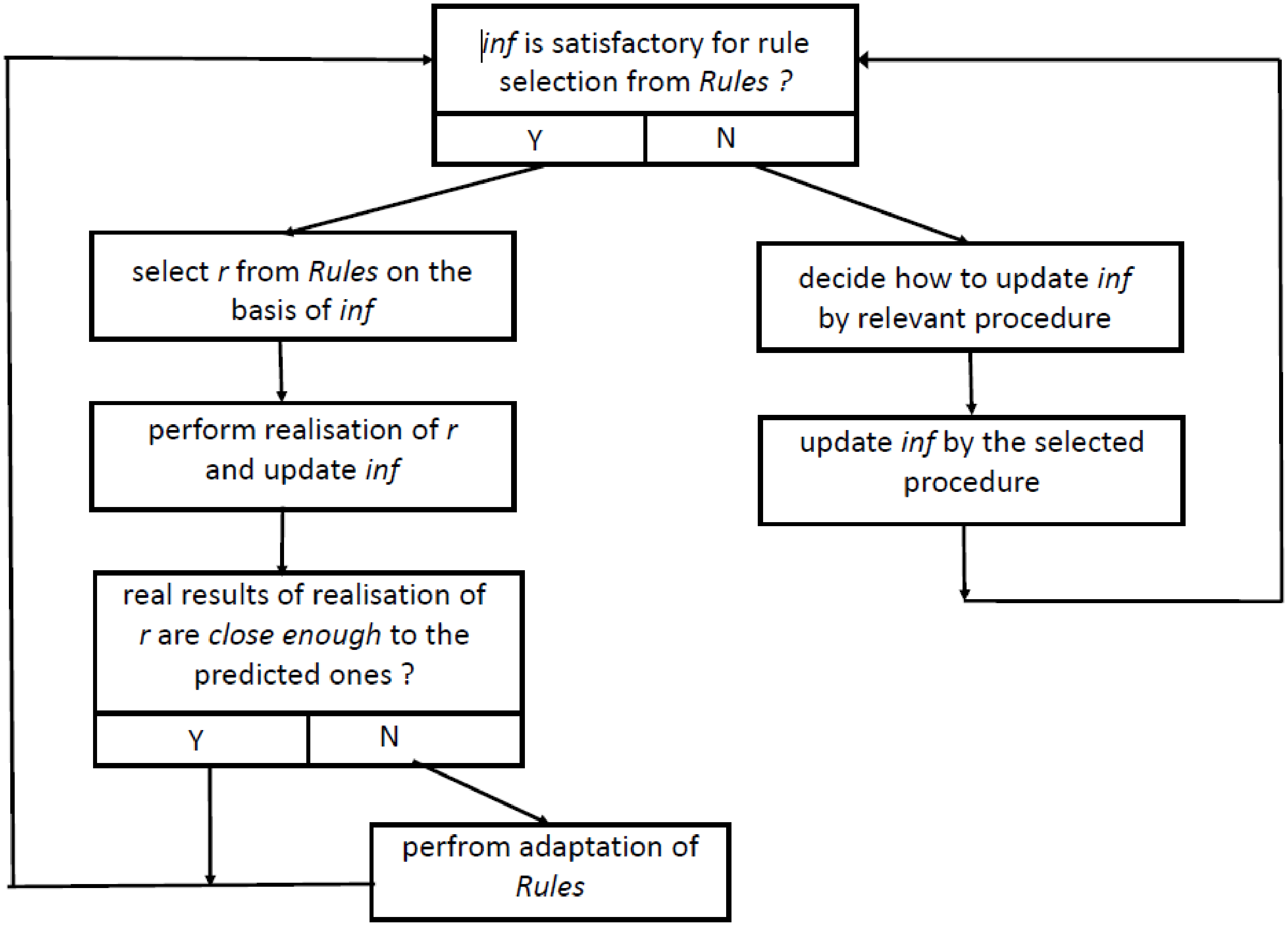
Control is involved in establishing associations between the informational and physical layers by implementing transformations (*tr*) through its implementation module (IM) (physical semantics).



Control is initiating communications between the informational layer and the physical layer using relevant c-granules (generated by its IM), allowing the collection of properties of perceived physical objects and their interactions within the informational layer.

NETWORK OF C-GRANULES INTERACTING WITH ABSTRACT AND PHYSICAL OBJECTS

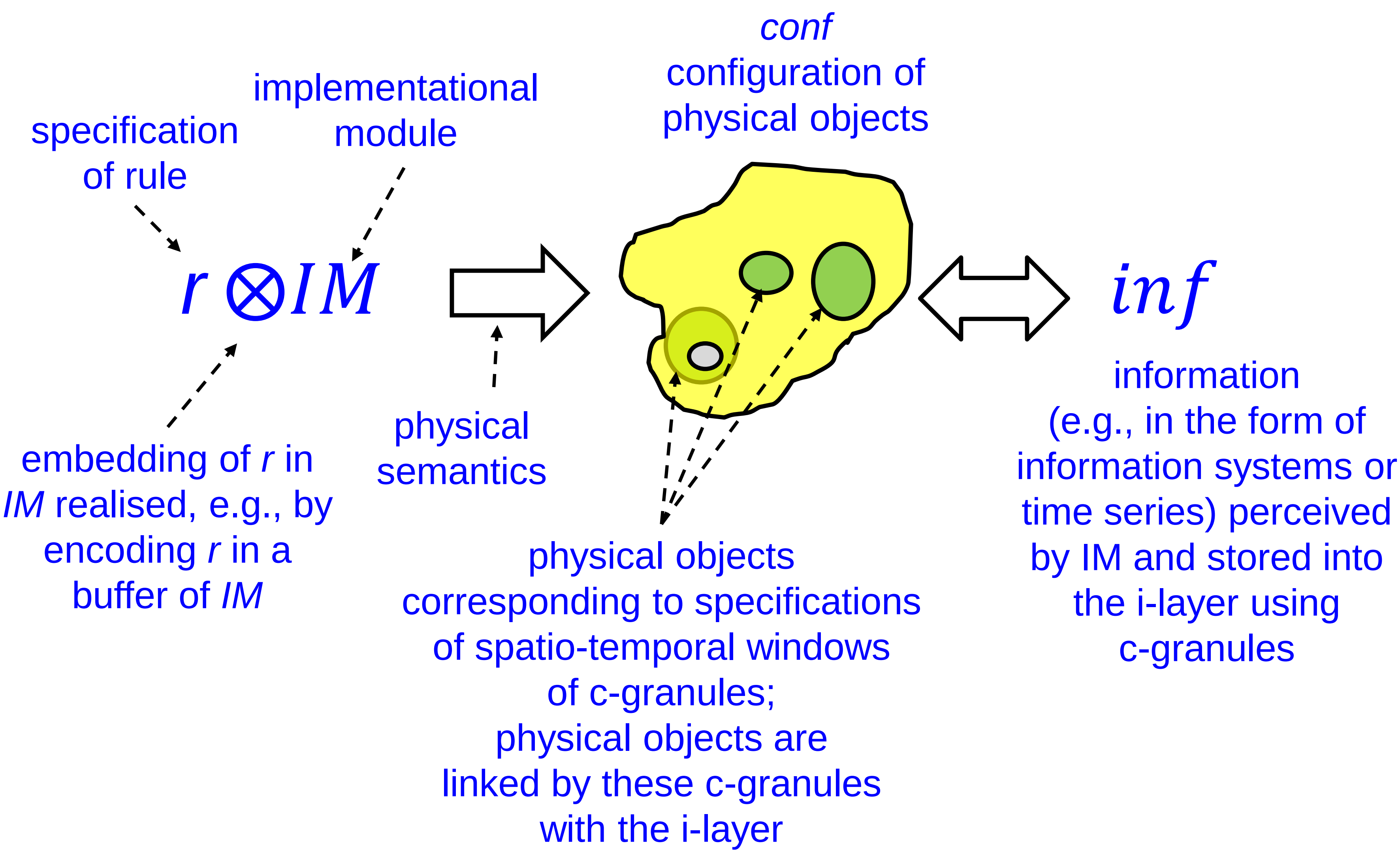
REASONING SUPPORTING BASIC CONTROL CYCLE



PHYSICAL SEMANTICS IS REALIZED BY IMPLEMENTATIONAL MODULE (IM) A SUB-GRANULE OF C-GRANULE CONTROL

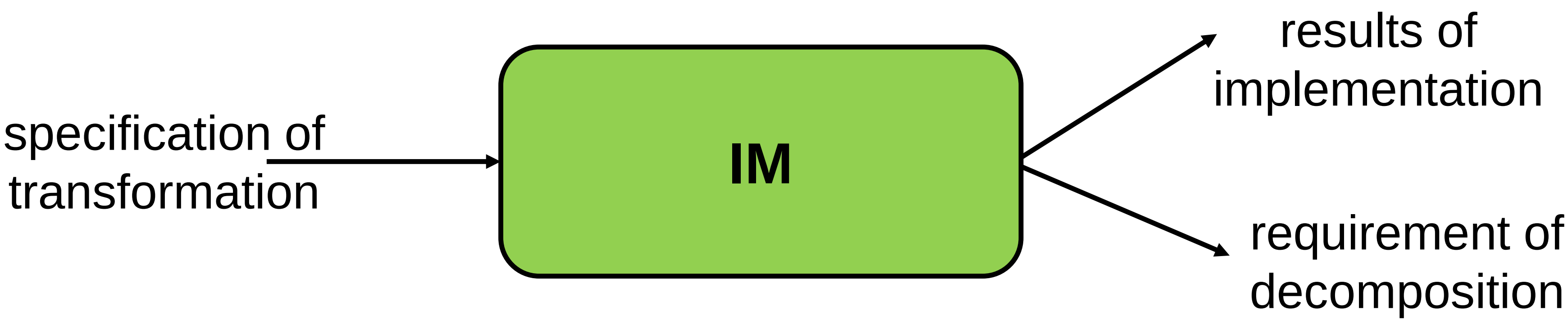
IM IS ABLE TO GENERATE OF NEW C-GRANULES WITH LINKS (POINTERS) BETWEEN ABSTRACT AND PHYSICAL OBJECTS. BY USING THESE C-GRANULES THE CONTROL PERCEIVES PROPERTIES OF PHYSCAL OBJECTS AND THEIR INTERACTIONS (BELONGING TO THE SCOPE OF THESE C-GRANULES) IN THE PHYSICAL WORLD

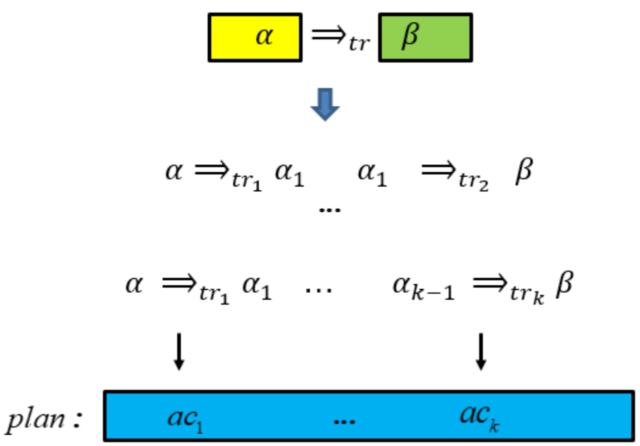
PHYSICAL SEMANTICS: INTUITION



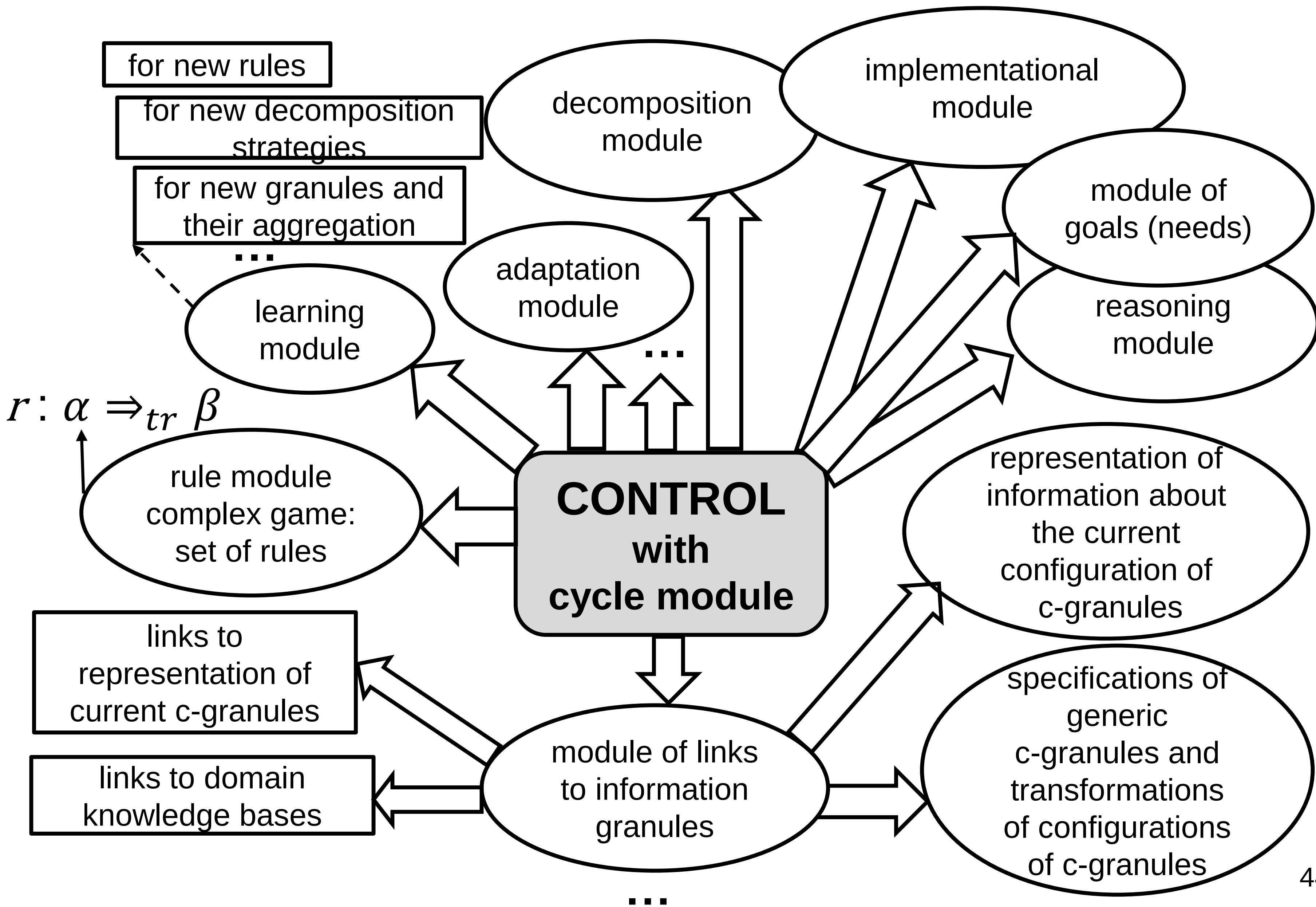
IMPLEMENTATIONAL MODULE (IM)

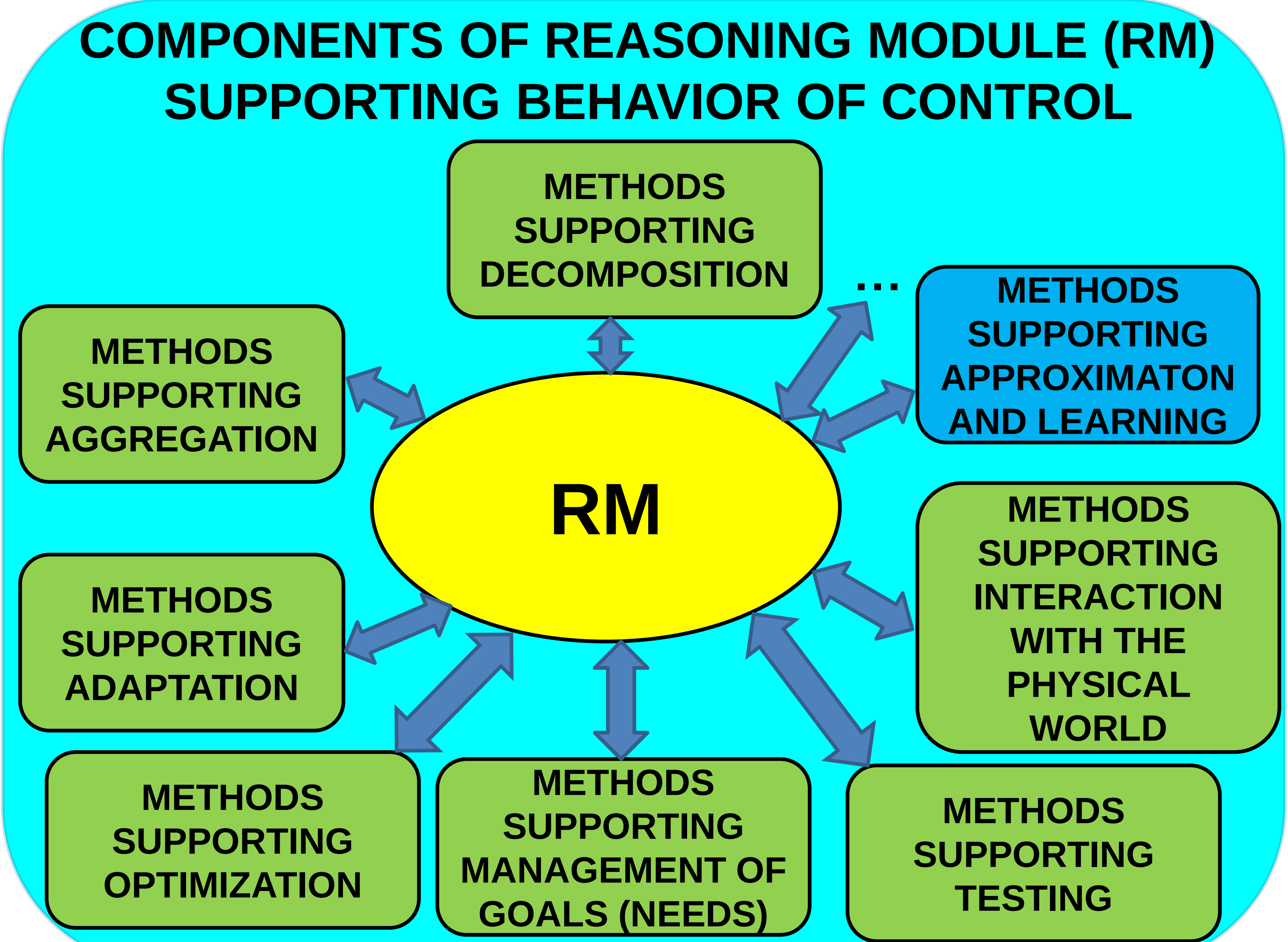
IM plays a crucial role in interaction of abstract and physical objects; IM realizes physical semantics





MODULES OF C-GRANULE CONTROL




COMPONENTS OF REASONING MODULE (RM)
SUPPORTING BEHAVIOR OF CONTROL
METHODS SUPPORTING DECOMPOSITION
...
METHODS SUPPORTING APPROXIMATON AND LEARNING
METHODS SUPPORTING AGGREGATION
RM
METHODS SUPPORTING INTERACTION WITH THE PHYSICAL WORLD
METHODS SUPPORTING ADAPTATION
METHODS SUPPORTING OPTIMIZATION
METHODS SUPPORTING MANAGEMENT OF GOALS (NEEDS)
METHODS SUPPORTING TESTING

SOME CHALLENGES CONCERNING REASONING

- Practical judgment
- Analogy based reasoning
- Experience based reasoning
- Perception based reasoning
- Common sense reasoning

PRACTICAL JUDGMENT

Practical judgment is not algebraic calculation. Prior to any deductive or inductive reckoning, the judge is involved in selecting objects and relationships for attention and assessing their interactions. Identifying things of importance from a potentially endless pool of candidates, assessing their relative significance, and evaluating their relationships is well beyond the jurisdiction of reason

Leslie Paul Thiele: The Heart of Judgment Practical Wisdom, Neuroscience, and Narrative. Cambridge University Press 2006

MELANIE MITCHELL
Santa Fe Institute

The quest for machines that can make abstractions and analogies is as old as the AI field itself, but the problem remains almost completely open.

Melanie Mitchell: Abstraction and Analogy-Making in Artificial Intelligence, Annals Reports of the New York Academy of Sciences 1505(1) 79-101 (2021)

We do not have yet formal reasoning for experience based reasoning working in IS's

However,

IS's on the basis of data analysis can help domain expert in this kind of reasoning.

Human experts and/or chatbots can help IS's to improve reasoning, e.g., in inducing classifiers.

Human-Centered AI, Human-in-the-Loop ML

SOME CHALLENGES CONCERNING REASONING (cont.)

Reasoning supporting

- optimization
- decomposition
- Adaptation (see co-evolution in the book by Holland)
- negotiation and conflict resolving
- searching for new relevant data and knowledge (*where*?, *what*?, *when*?, *how*?)
- discovery of granular computations according to given specifications (drug discovery, automatic design of robots, discovery of strategies on financial markets etc.)
- construction of quality measures over granular computations
- risk management in generation of approximate solutions of high quality
- …

COMPUTING WITH WORDS– LOTFI A. ZADEH

[…] Manipulation of perceptions plays a key role in human recognition, decision and execution processes. As a methodology, computing with words provides a foundation for a computational theory of perceptions - a theory which may have an important bearing on how humans make - and machines might make – perception - based rational decisions in an environment of imprecision, uncertainty and partial truth.

[…] computing with words, or CW for short, is a methodology in which the objects of computation are words and propositions drawn from a natural language.

Lotfi A. Zadeh1: From computing with numbers to computing with words – From manipulation of measurements to manipulation of perceptions. IEEE Transactions on Circuits and Systems 45(1), 105–119 (1999)

JUDEA PEARL- TURING AWARD 2011

for fundamental contributions to artificial intelligence through the development of a calculus for probabilistic and causal reasoning

Traditional statistics is strong in devising ways of describing data and inferring distributional parameters from sample. Causal inference requires two additional ingredients:

- *a science-friendly language for articulating causal knowledge*,

and

- *a mathematical machinery for processing that knowledge, combining it with data and drawing new causal conclusions about a phenomenon*.

Judea Pearl: Causal inference in statistics: An overview. Statistics Surveys 3, 96-146 (2009)

GRANLAR COMPUTATIONS

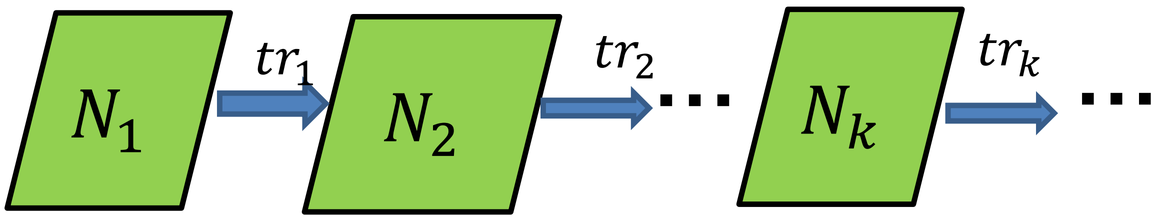
GRANULAR COMPUTATIONS IN IGrC and IGrC

GrC:

$N_1, N_2 \ldots, N_k$ -- granular networks in the abstract space

$tr_1, tr_2, \ldots, tr_k$ -- transformations realized in the abstract space

The control of c-granules, whether cooperating or competing with other c-granules, aiming to generate a granular computation along which is constructed an approximate solution of the problem to be solved to the required quality.



IGrC:

$N_1, N_2 \ldots, N_k$ -- granular networks in the abstract and physical spaces

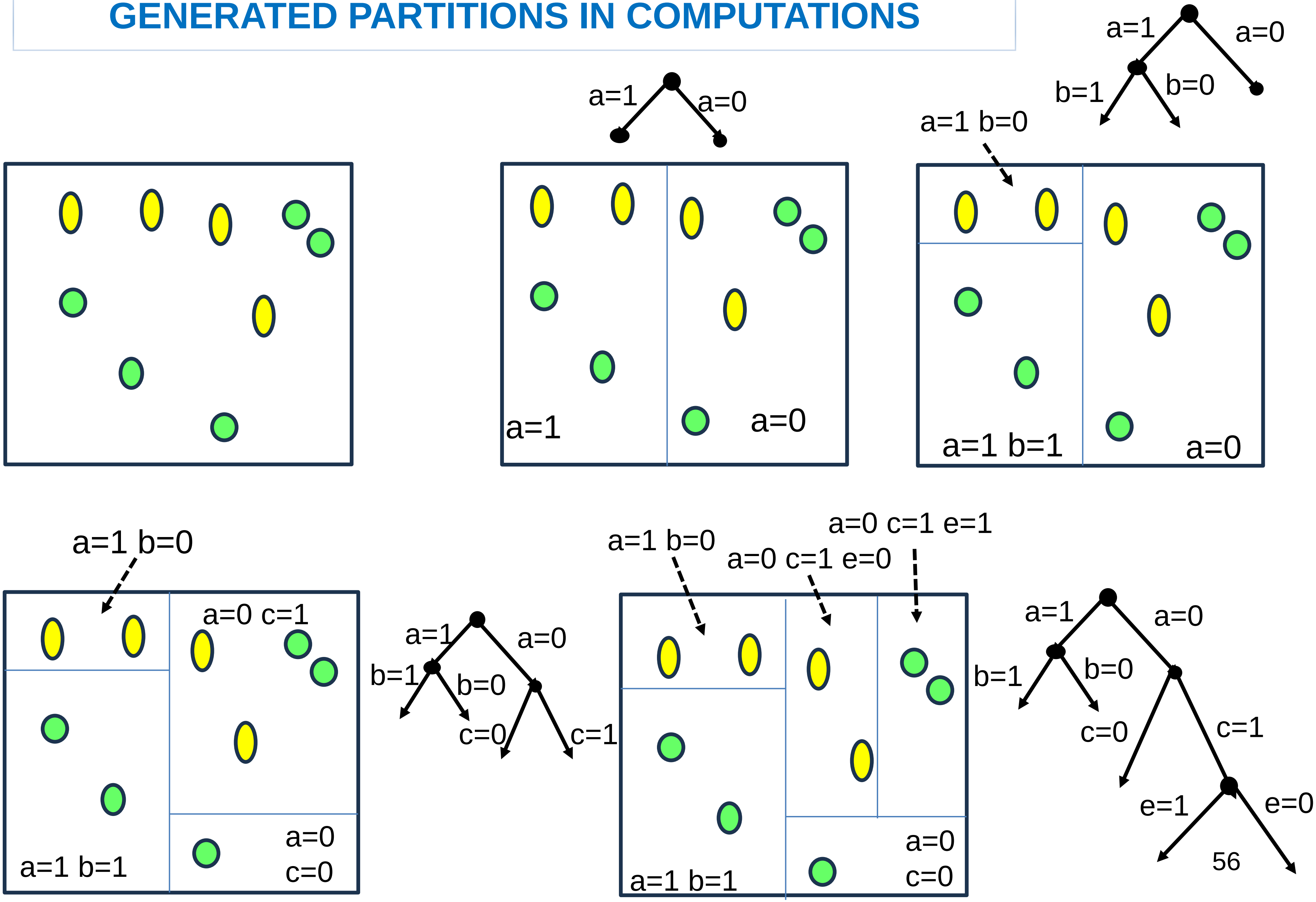
$tr_1, tr_2, \ldots, tr_k$ -- transformations realized in the abstract and physical spaces

The control of c-granules, whether cooperating or competing with other c-granules, engages in interaction with the physical space, aiming to generate a granular computation along which is constructed an approximate solution of the problem to be solved to the required quality.

ILLUSTRATIVE EXAMPLE

SEMI-OPTIMAL DECISION TREE CONSTRUCTED ALONG PARTITIONS GENERATED IN COMPUTATIONS REALIZED BY CONTROL OF C-GRANULE

EXAMPLE: DECISION TREE CONSTRUCTION ALONG GENERATED PARTITIONS IN COMPUTATIONS



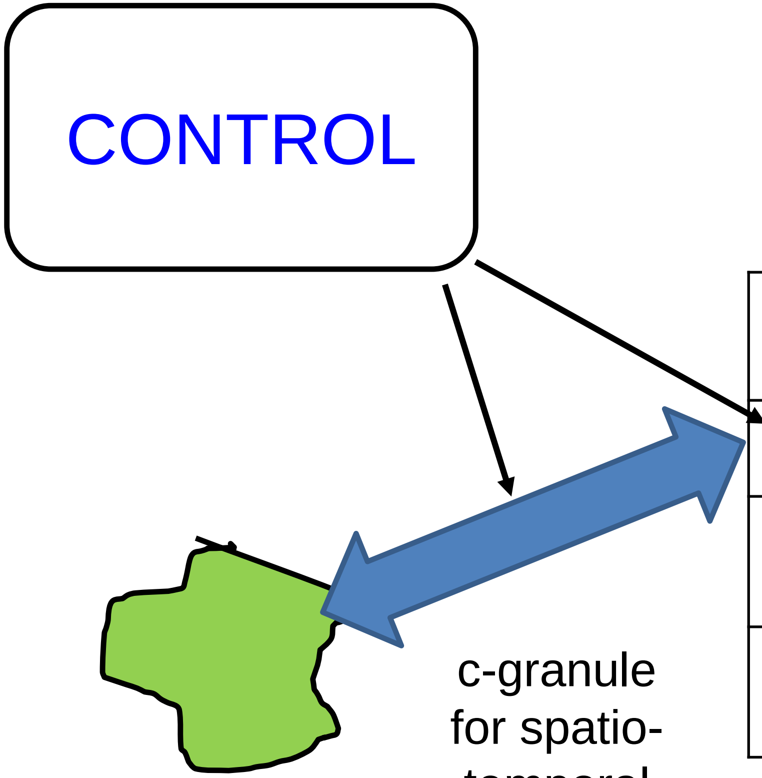
EXAMPLES OF DOMAINS WHERE DISCOVERING HIGH-QUALITY APPROXIMATE SOLUTIONS IS IMPORTANT

- Discovery of learning algorithms and construction of classifiers
- Automatic design of robots
- Drug discovery
- Algorithmic Trading
- Generative AI
- Modeling cognitive computers
- …

CHALLENGE:
DEVELOPING THE FOUNDATIONS BASED ON IGrC AND RS FOR THE DESIGN AND ANALYSIS OF DISCOVERY SYSTEMS FOR DIFFERENT DOMAINS

ROUGH SETS (RS) & IGrC

C-GRANULES WITH CONTROL AND INFORMATION SYSTEMS UNDER CONTROL OF C-GRANULES



	a_1	a_2	…	a_m
w_1	v_1	v_2	…	v_m
	…	…	…	…

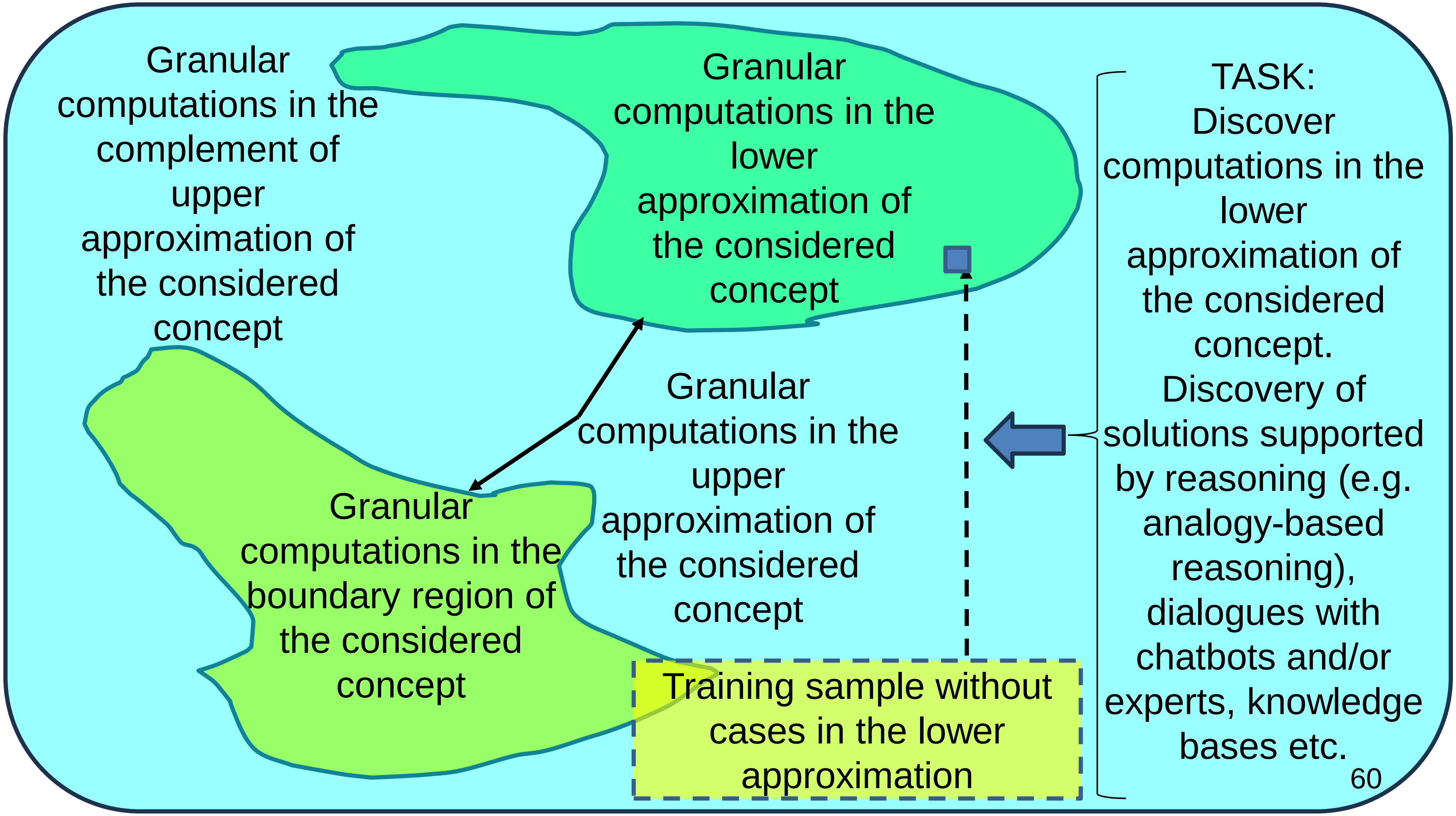
c-granule for spatio-temporal window(s) w_1

dynamics of information systems determined by control and its interaction with the environment

RS & IGrC IN FOUNDATIONS OF APPROXIMATE PROBLEM SOLVING IN AI

APPROXIMATION AREAS OF CONCEPT:

GRANULAR COMPUTATIONS WITH HIGH-QUALITY SOLUTIONS IN THE DOMAIN OF COMPUTATIONS OF C-GRANULE CONTROL



RS – CURRENT APPROACH

Basic concept:
Approximation space

Basic task:
Approximation of concepts

RS & IGrC
FUTURE APPROACH

Basic concept:
Approximate reasoning processes supporting

(i) generation of rough set based granular computations in interaction with the abstract and physical worlds over dynamically discovered rough set based granular networks and

(ii) for a given problem specification to c-granule(s), construction of "abstract and/or physical" approximate solutions of appropriate quality along these granular computations in the form of granules.

Basic task:
Discovery of approximate solutions to problems of appropriate quality based on discovery of rough set based complex game teams over rough set based granular networks

SUMMARY

COMPARISON OF GrC & IGrC

	GrC	IGrC
GENERAL FEATURES OF COMPUTING MODEL		
based on the abstract Turing computation model	YES	NO
computations are pure mathematical objects	YES	NO
issues of language, reasoning, perception and action are brought into sync	NO	YES
modeling of perception of situations (objects and their interactions) in the physical world is provided	NO	YES
advanced reasoning tools based on the computing model that support the control of computations involving both abstract and physical objects are being developed and utilized in the computing model	NO	YES
MAIN FEATURES OF GRANULES		
abstract semantics of (information) granules is provided	YES	YES
physical semantics of (complex) granules is provided	NO	YES
features (attributes) of granules defined using the abstract space only	YES	NO
features (attributes) of granules dependent on interaction with physical objects	NO	YES
granules are equipped with control	NO	YES
the dynamics of granules are defined a priori in the abstract space only	YES	NO
the dynamics of granules depends on physical laws, their (internal and external) control and interactions with the environment	NO	YES
associations between abstract and physical objects related to granules are being constructed and used in the computing model	NO	YES
skills for encoding information into physical objects provided in the computing model	NO	YES
skills for decoding information from physical objects provided in the computing model	NO	YES
changes of granules are being made based on the abstract space only (they are are restricted to their abstract parts only)	YES	NO
changes of the information represented in the i-layers of granules are being made based on the abstract space only	YES	NO
changes of the information represented in granules are also being made based on interaction with physical objects	NO	YES
STATES, TRANSITION, COMPUTATIONS IN COMPUTING MODEL		
state of c-granule: c-granule (with its abstract and physical objects) at a given moment of (local) time	NO	YES
transition relation (association) defined based on information in the abstract space only	YES	NO
transition relation (association) dependent on interactions with physical objects	NO	YES
computations consist of abstract states only	YES	NO
computations depend on physical laws	NO	YES
adaptation of steering of granular computations provided by control of granules dependent on interaction with physical objects	NO	YES

FOUNDATIONS BASED ON IGrC & RS FOR IS's DEALING WITH COMPLEX PHENOMENA

Tomorrow, I believe, we will use
[IS's]
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)

IGrC: SUMMARY

The IGrC model was created as the basis for the design and analysis of c-granules, in particular IS's. The proposed IGrC model differs from the classical Turing model by synchronizing four components: language, reasoning, perception, and action. In the IGrC model, granular computations form the basis for reasoning that supports problem solving by c-granules.

Problem solving (or decision support) using c-granules (IS's) requires a proper understanding of real-world situations consisting of configurations of interacting objects. Therefore, the control of c-granules must include skills for perceiving situations in the physical world enabling the formation of associations between physical and abstract objects. These skills are supported by reasoning over granular computations performed by the control of c-granules. Consequently, these computations cannot be confined to the abstract space alone. Moreover, they depend on physical laws.

IGrC: SUMMARY

The generalization of GrC to IGrC was proposed to support the design of IS's that deal with complex phenomena, which can be treated in IGrC as examples of complex granules (c-granules) with control. To make such systems successful, it is necessary to enable their continuous interaction with the physical world. The control of c-granules can properly implement the physical semantics of specified transformations of c-granules in the physical world. This implementation is based on the discovery of relevant configurations of physical objects, which provides the basis for perceiving relevant data about these objects and their interactions through the control of c-granules. Furthermore, to ensure the success of the designed IS's, these configurations must adaptively change to enable the perception of relevant data that will make it possible to construct high-quality models on which the behavior of the IS's is based. Unlike information granules from GrC, the correct implementation of c-granule transformations cannot be restricted to the abstract space. An important property of the IS's discussed here is that they cannot be separated from interactions with the physical world. They cannot be confined to an abstract space.

TOWARD
BRINGING INTO SYNC
FOUR IMPORTANT AREAS OF RESEARCH ON RS:
LANGUAGE, REASONING, PERCEPTION, AND ACTION

IGrC papers at: https://dblp.uni-trier.de/pers/hd/s/Skowron:Andrzej
F. P. Brooks, Jr.: The Mythical Man-Month: Essays on Software Engineering, Anniversary Edition. Addison-Wesley, 1995.
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C. L. Ortitz Jr.: Why we need a physically embodied Turing test and what it might look like, AI Magazine 37: 55–62 (2016). doi.org/10.1609/aimag.v37i1.2645
Z. Pawlak: Rough sets. Theoretical Aspects of Reasoning About Data. Kluwer, 1991. doi.org/10.1007/978-94-011-3534-4
W. Pedrycz: Granular Computing. Analysis and Design of Intelligent Systems. CRC Press, Taylor & Francis, 2013. doi.org/10.1201/9781315216737
A.Skowron. A. Jankowski: Rough Sets and Interactive Granular Computing. Fundamenta Informaticae 147 (2-3): 371–385 (2016). doi.org/10.3233/FI-2016-1413
A. Skowron, A. Jankowski, and S. Dutta: Interactive Granular Computing. Granular Computing 1: 95–113 (2016). doi.org/10.1007/s41066-015-0002-1
A.Skowron, A. Jankowski, S. Dutta: Interactive Granular Computing: Toward Computing Model for Complex Intelligent Systems. FedCSIS 2025.
A. Skowron, D. Ślęzak: Rough Sets in Interactive Granular Computing: Toward Foundations for Intelligent Systems Interacting with Human Experts and Complex Phenomena. IJCRS 2023. doi.org/10.1007/978-3-031-50959-9

THANK YOU!