# Biologically and psychologically inspired modelling in BICA

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# Self-presentation

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- Research Fellow in Laboratory of Dynamic intelligent systems of Federal Research Center "Computer Science and Control" of the Russian Academy of Sciences.
- Research Fellow and Senior Lecturer in National Research University High School of Economics (Faculty of Computer Science)
- Assistant Lecturer in Moscow Institute of Physics and Technology (Department of Computer Science).
- Member of the Editorial Board of the Biologically Inspired Cognitive Architectures (BICA Journal).
- Regular Fellow of the Russian Association of the Artificial Intelligence (RAAI).
- Member of The Biologically Inspired Cognitive Architectures Society (BICA Society).
- Member of the NEURONET workgroup of the National Technology Initiative (ASI).
- Head of research projects for young scientists of Russian Foundation for Basic Research (RFBR).

# Research institute

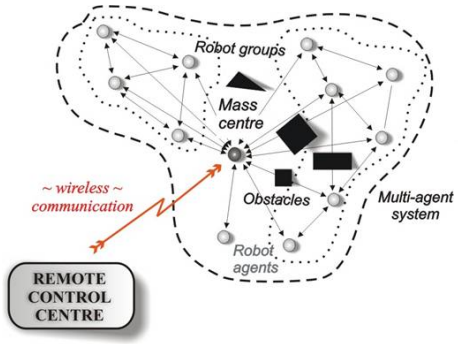
Federal Research Centre "Computer Science and Control" of **Russian Academy of Sciences**

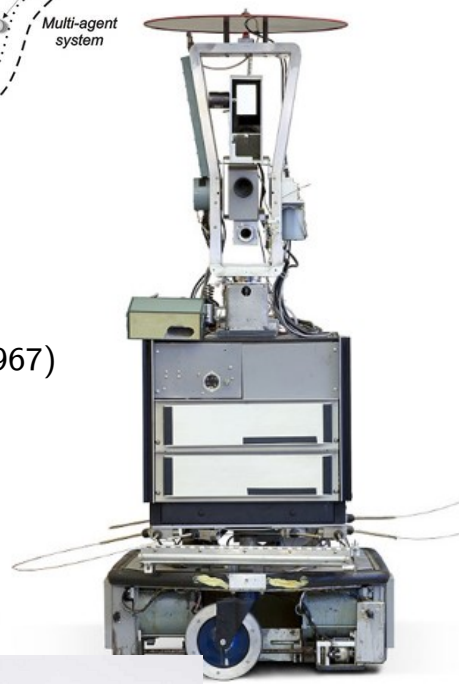
**Includes**: Institute for Systems Analysis, Computational Center of Russian Academy of Sciences, Institute of Informatics Problems.

**R&D areas**: Computer Science, Artificial Intelligence, Cognitive Psychology, Linguistics, Search Engines, Natural Language Processing, Cognitive Modelling, Control Systems, Computational Math, Patter Recognition, Data Analysis, Semiotics, Robotics, Economics.

# Nowadays BICA — what is missing?

- Architectures for real robot control.
- Symbolic-subsymbolic processing.
- Integrated model of symbolic processing.
- Full multiagent integration.
- Coalition management and formation.
- Human-robot interaction support.



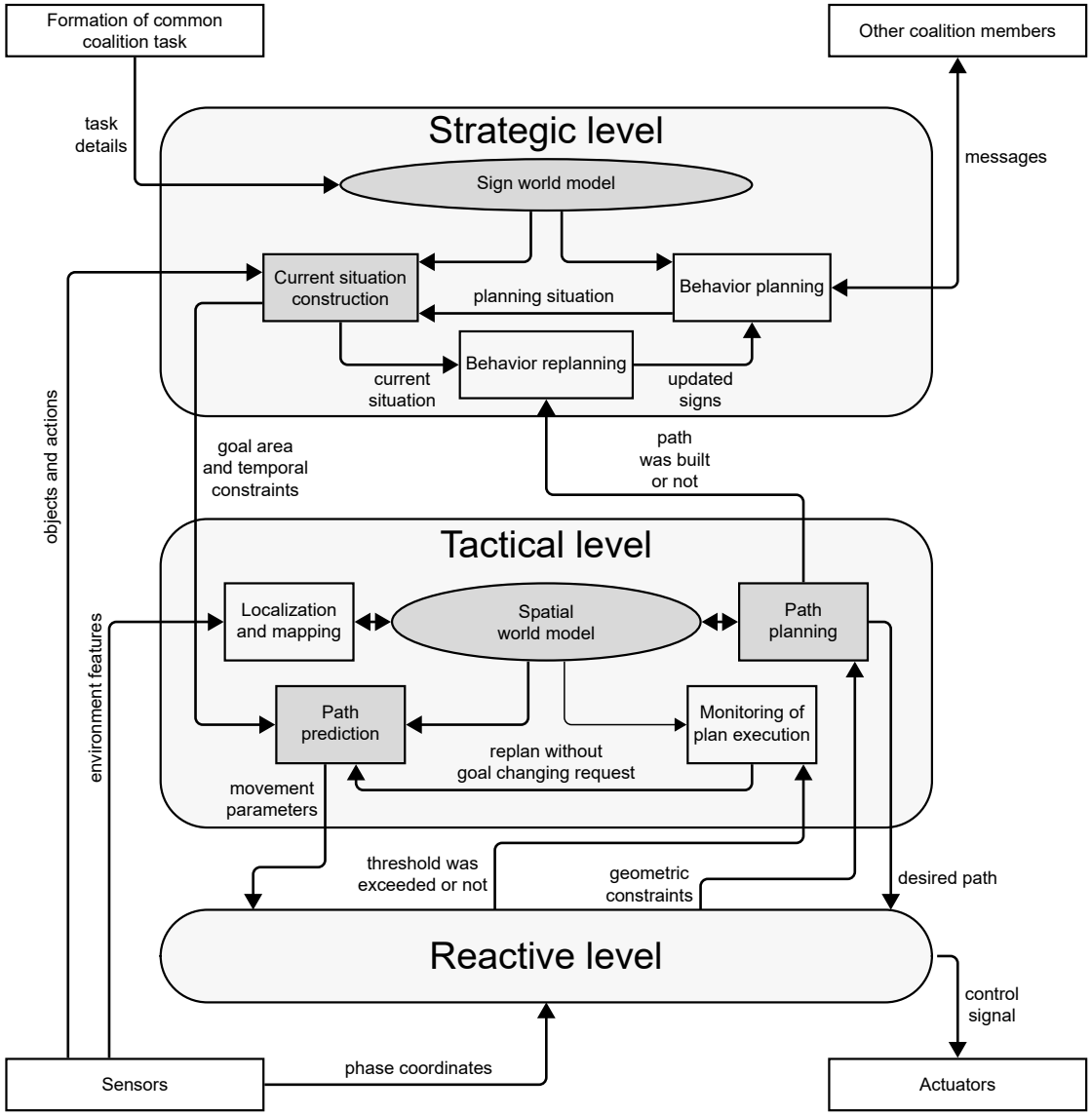
Shakey (Circa 1967)


Chella, A., M. Frixione, and S. Gaglio. "Anchoring symbols to conceptual spaces: The case of dynamic scenarios". 2003.

Lieto, Antonio. "A Computational Framework for Concept Representation in Cognitive Systems and Architectures: Concepts as Heterogeneous Proxytypes". 2014.

Besold, Tarek R. and Kai Uwe Kuhnberger. "Towards integrated neural-symbolic systems for human-level AI: Two research programs helping to bridge the gaps". 2015.

# STRL architecture



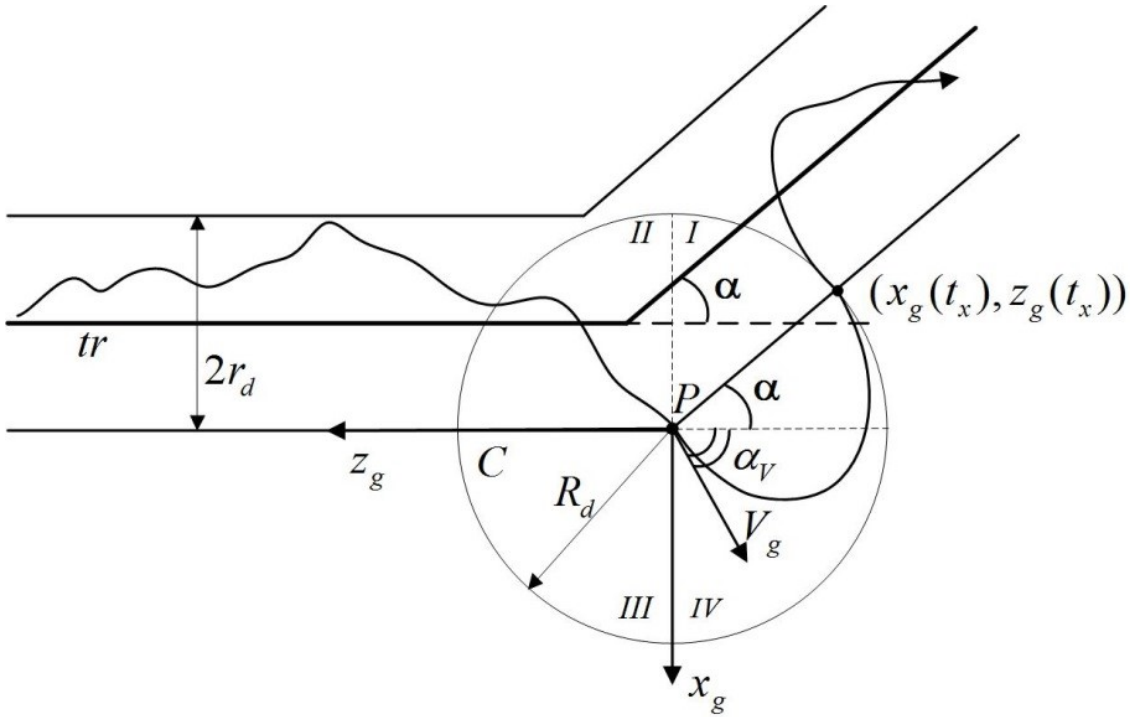

3 levels of control:

- **Strategic**: Behavior planning (including inter-agent communication
- **Tactic**: Path planning (including prediction and monitoring)
- **Reactive**: Path following taking into account agent's dynamic

Emel'yanov, S. et al. "Multilayer cognitive architecture for UAV control". 2016.

# Reactive level: SDRE technique

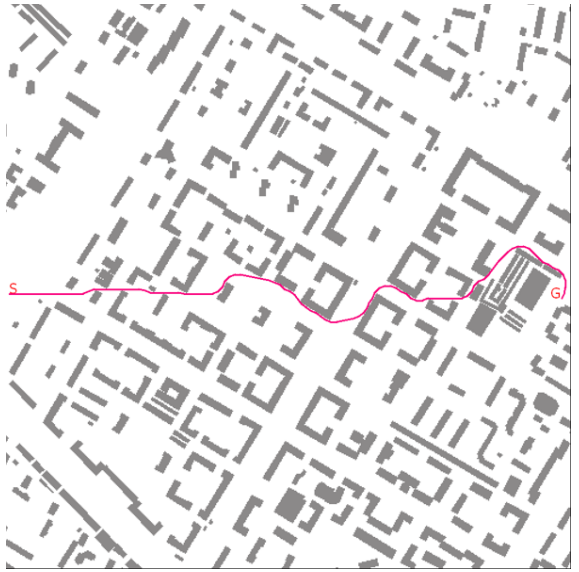
- Desired trajectory and UAV speed are received from the tactical level.
- Nonlinear control based on a special method of solving the State-Dependent Riccati Equation (SDRE).

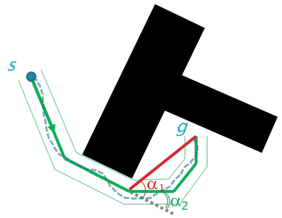



Yakovlev, K. S., D. A. Makarov, and E. S. Baskin. "Automatic path planning for an unmanned drone with constrained flight dynamics" , 2015

# Tactic level: 2 phases of path planning

1. Path prediction (fast, no angle constraints)
   - Using Theta* to find a path
   - Use this path to calculate angle constraints (on reactive level)
2. Angle constrained path planning
   - Using LIAN to find a path
     - Not that fast
     - No path can exist under constraint given



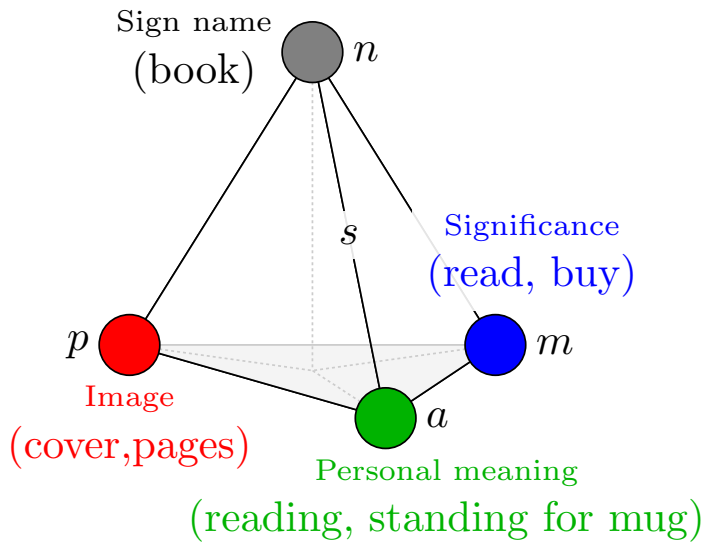



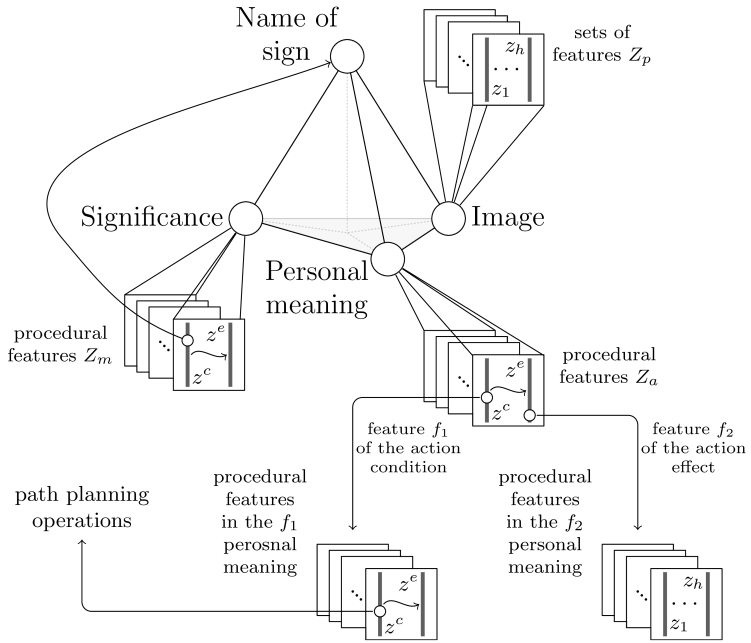

Nash, A. et al. "Theta*: Any-Angle Path Planning on Grids". 2010.
Yakovlev, K., E. Baskin, and I. Hramoin. "Grid-based angle-constrained path planning". 2015.

# Strategic level: Sign knowledge representation

Sign as a component of knowledge:

- cultural-historical approach of Vygotsky-Luria
- the theory of activity of Leontiev

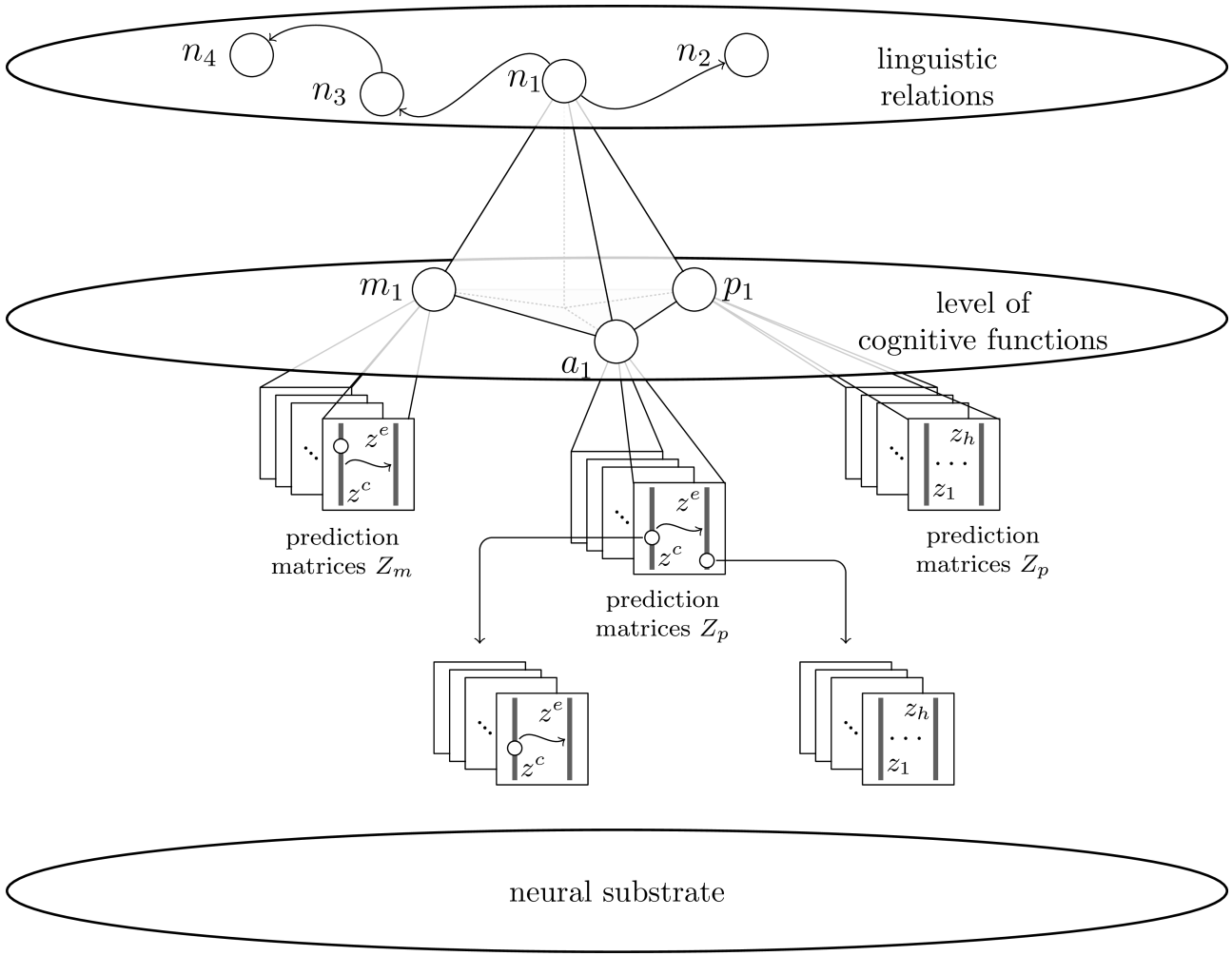



This structure is supported by neuropsychological data (Edelmen, Ivanitsky, Mountcastle etc.)


Edelman, G. M. *Neural Darwinism: The Theory Of Neuronal Group Selection*. 1987.
Ivanitsky, A. M. "Information synthesis in key parts of the cerebral cortex as the basis of subjective experience". 1997.
Mountcastle, V. B. *Perceptual Neuroscience. The Cerebral Cortex*. 1998.

# Sign world model

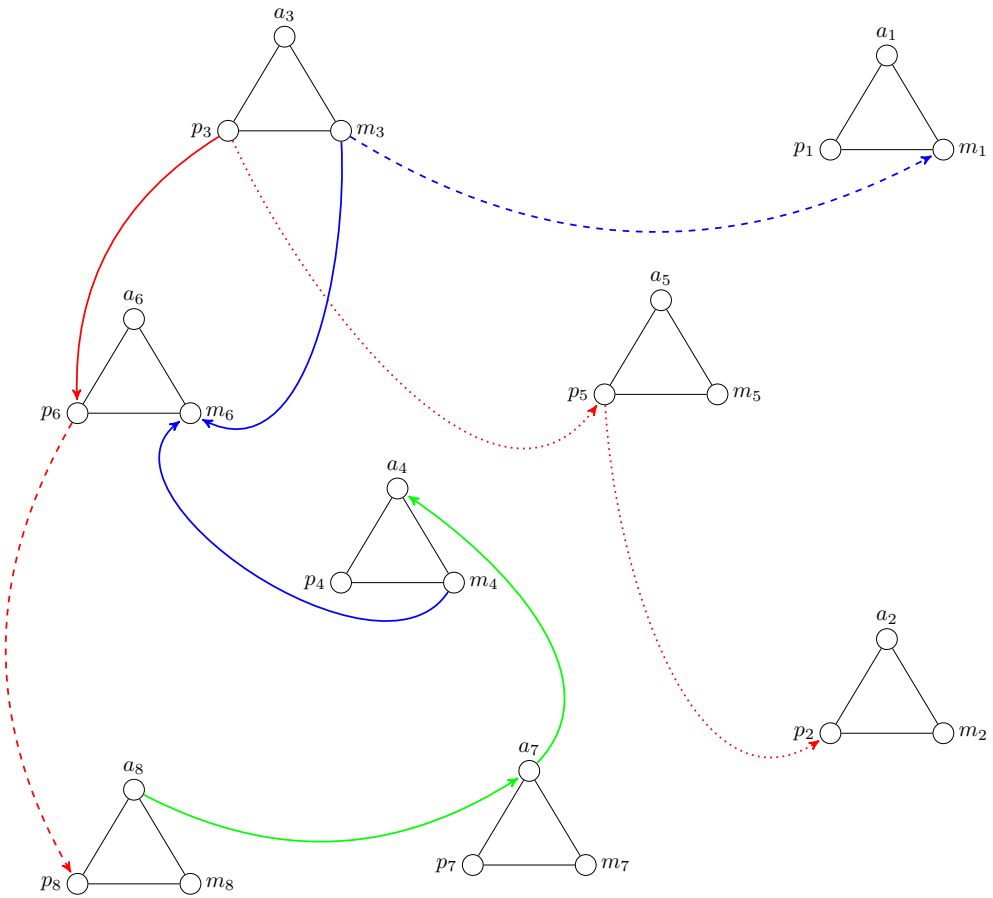




Osipov, G. S., A. I. Panov, and N. V. Chudova. "Behavior control as a function of consciousness. I. World model and goal setting". 2014.

— . "Behavior Control as a Function of Consciousness. II. Synthesis of a Behavior Plan". 2015.

# Sign world model

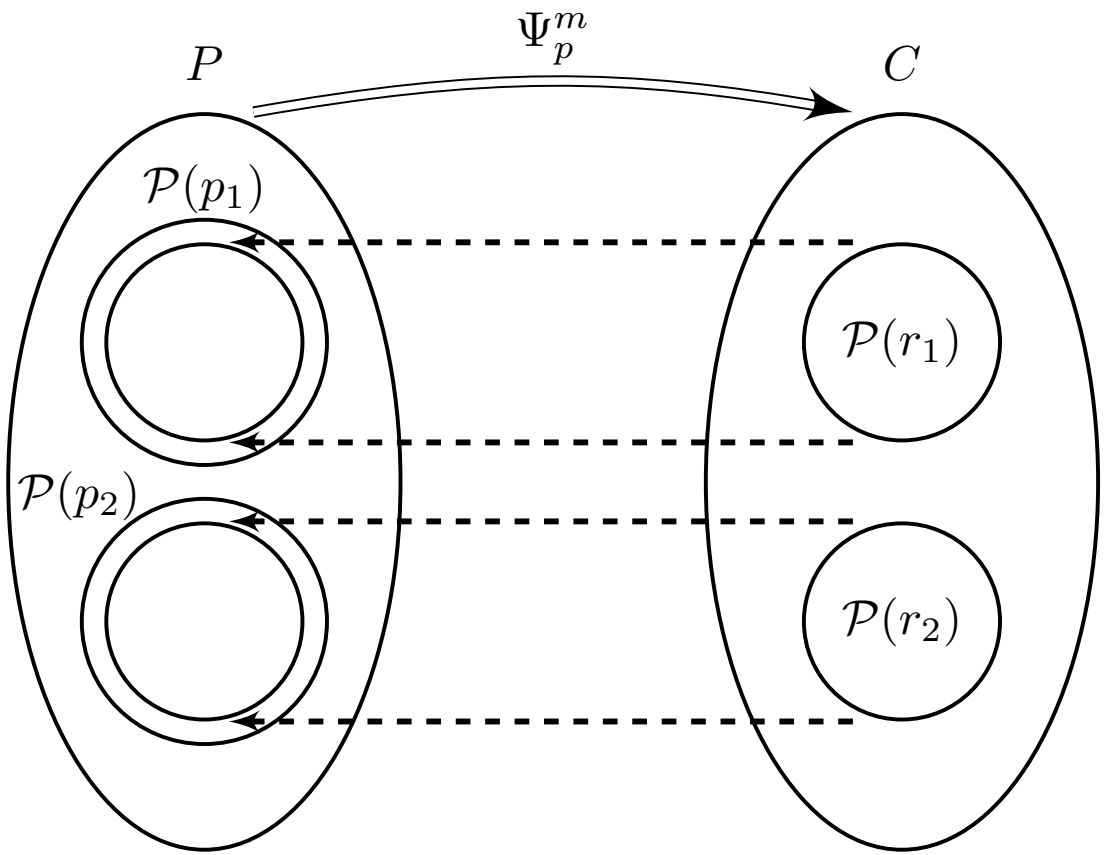



*Semiotic network*
$H = \langle H_P, H_A, H_M \rangle$ consisting of three semantic network:

- $H_P = \langle 2^P, \mathfrak{R}_P \rangle$ – semantic network on the set of sign images,
- $H_P = \langle 2^A, \mathfrak{R}_A \rangle$ – semantic network on the set of sign meanings,
- $H_P = \langle 2^M, \mathfrak{R}_M \rangle$ – semantic network on the set of sign significances.

Osipov, Gennady S. "Signs-Based vs. Symbolic Models". 2015.

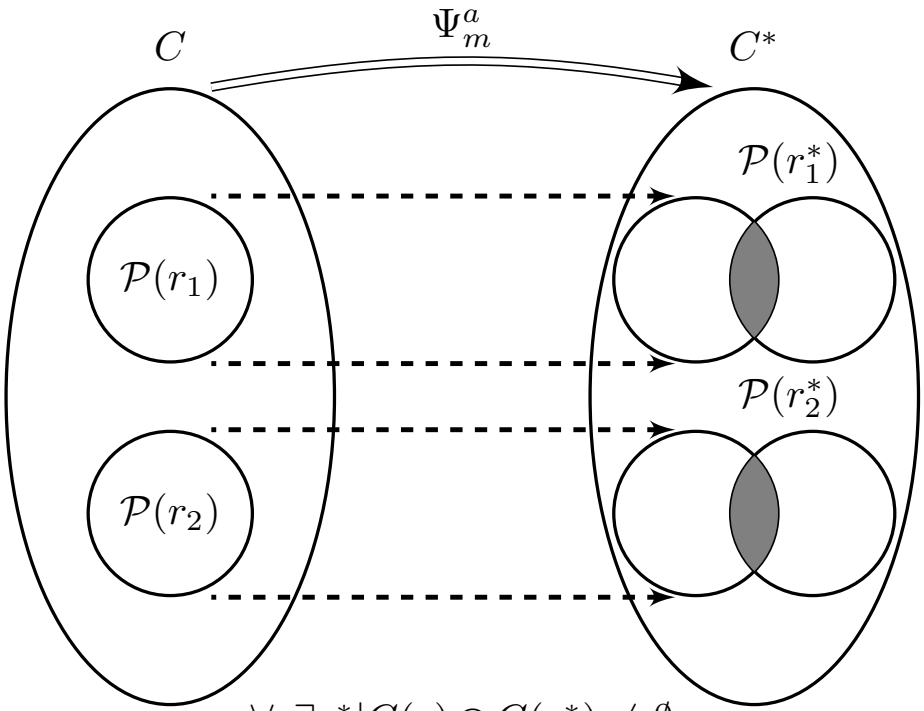
# Linking Operators



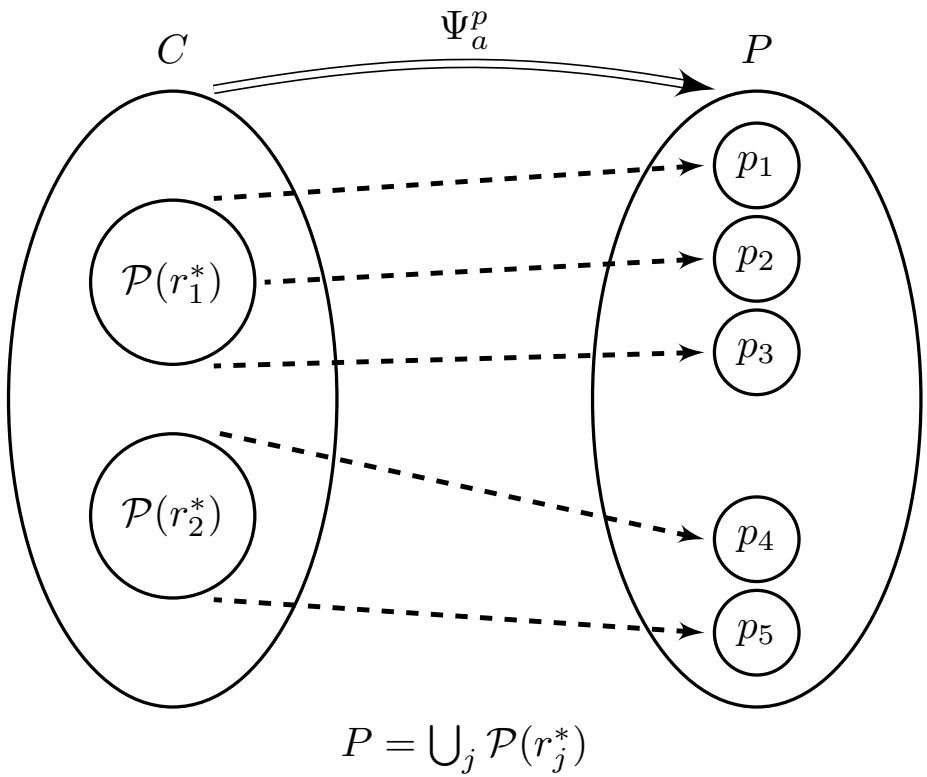

$$m = \{r | \mathcal{P}(r) \subseteq \mathcal{P}(p_i)\}$$

Linking an image and a significance.

# Linking Operators

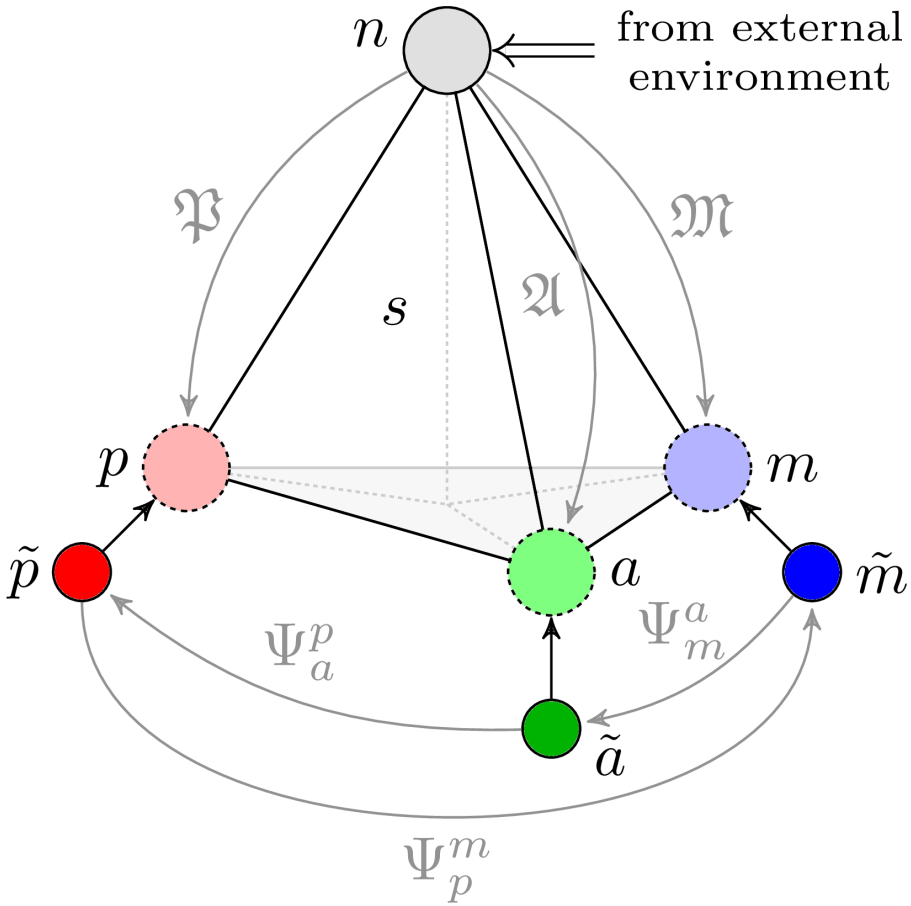



Linking a significance and a meaning.

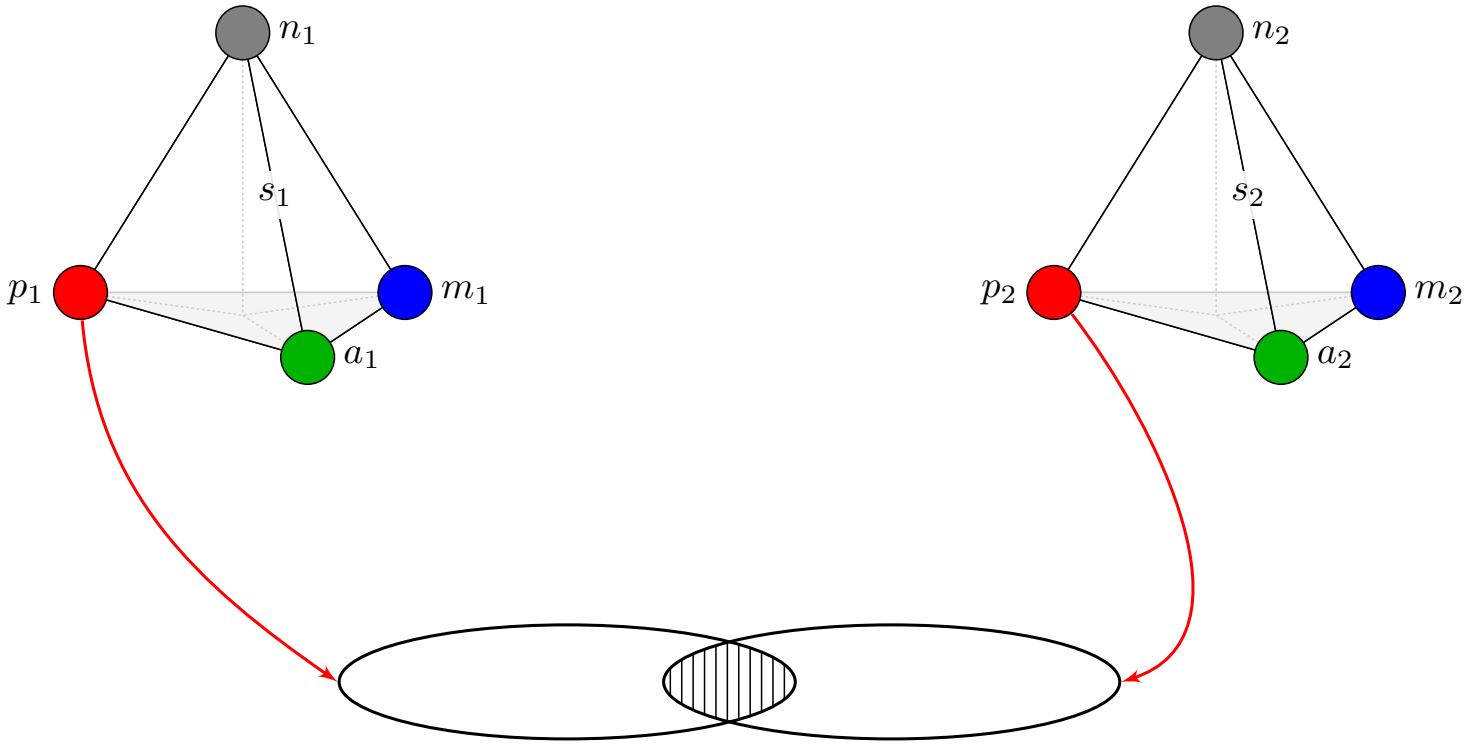



Linking a meaning and an image.

# Sign Naming


$n$
from external environment
$\mathfrak{P}$
$\mathfrak{M}$
$s$
$\mathfrak{A}$
$p$
$m$
$\tilde{p}$
$a$
$\tilde{m}$
$\Psi^p_a$
$\Psi^a_m$
$\tilde{a}$
$\Psi^m_p$

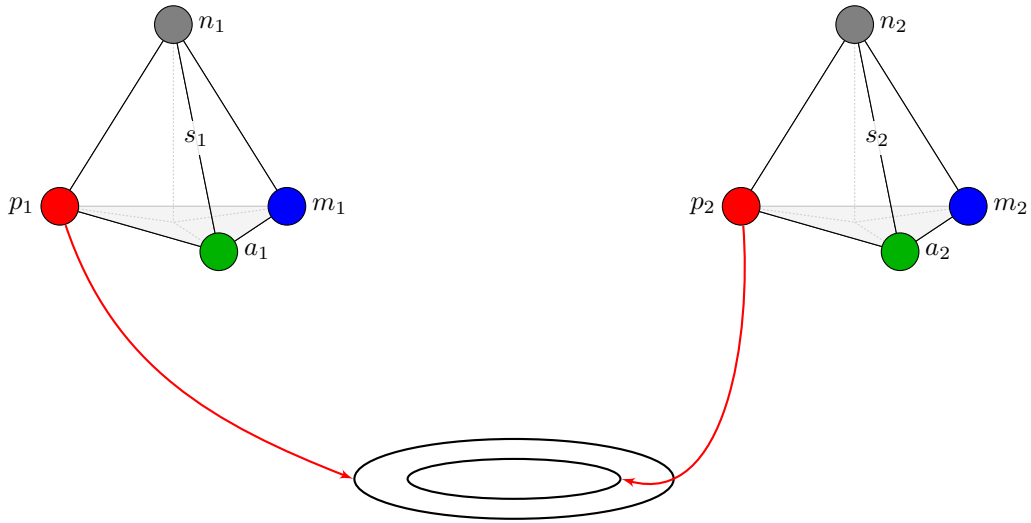
# Relations on sign components



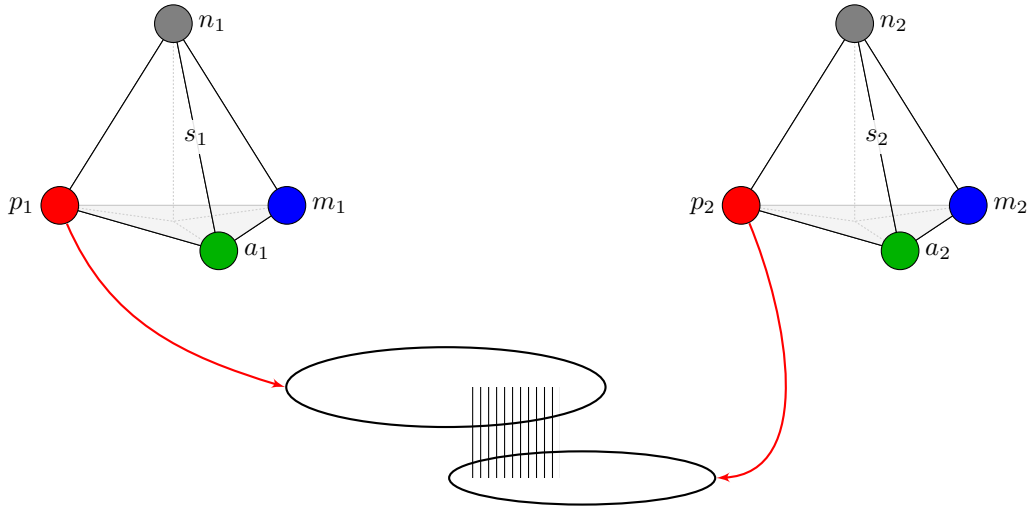

Similarity of images.

# Relations on sign components

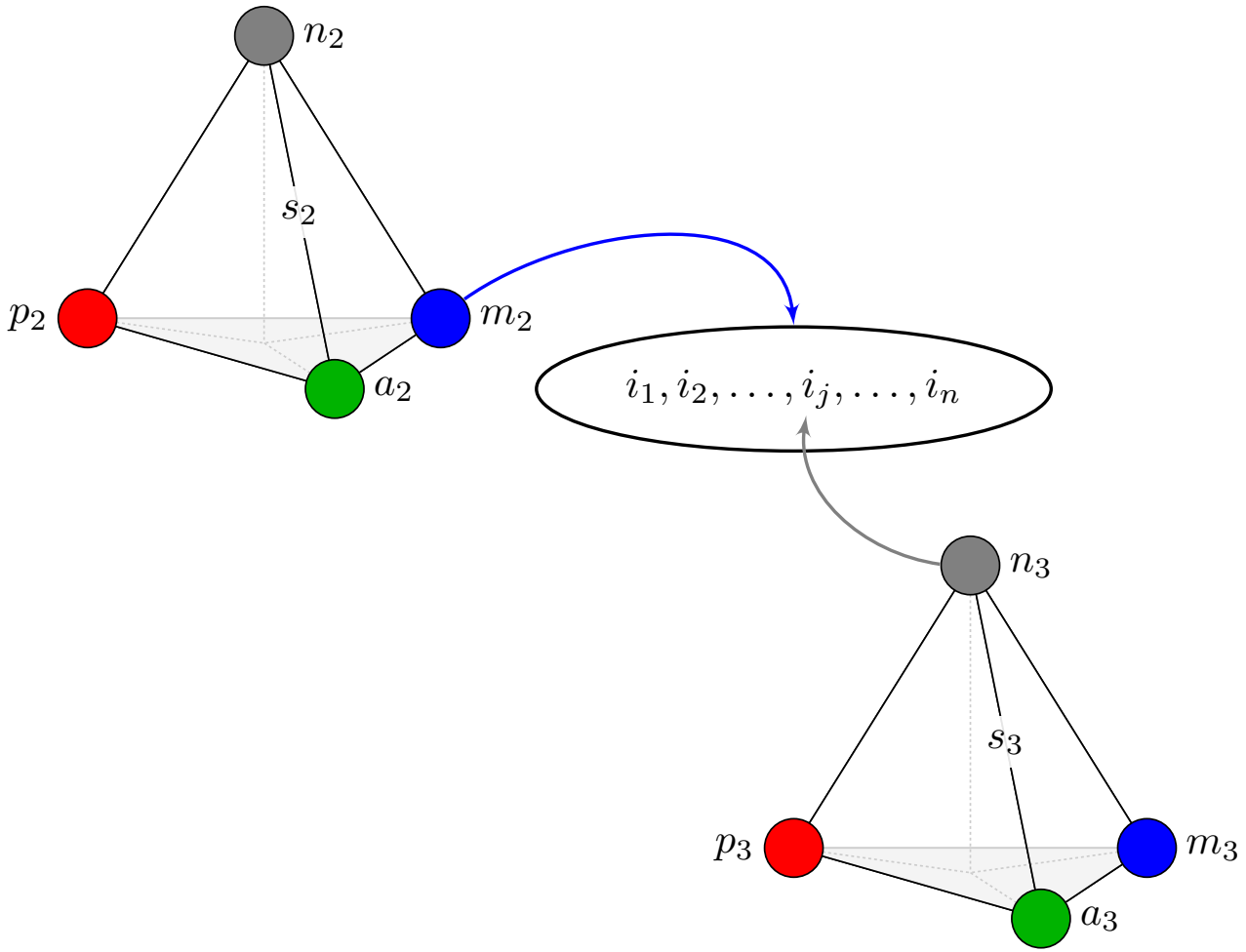
Inclusion of images:




Opposition of images:



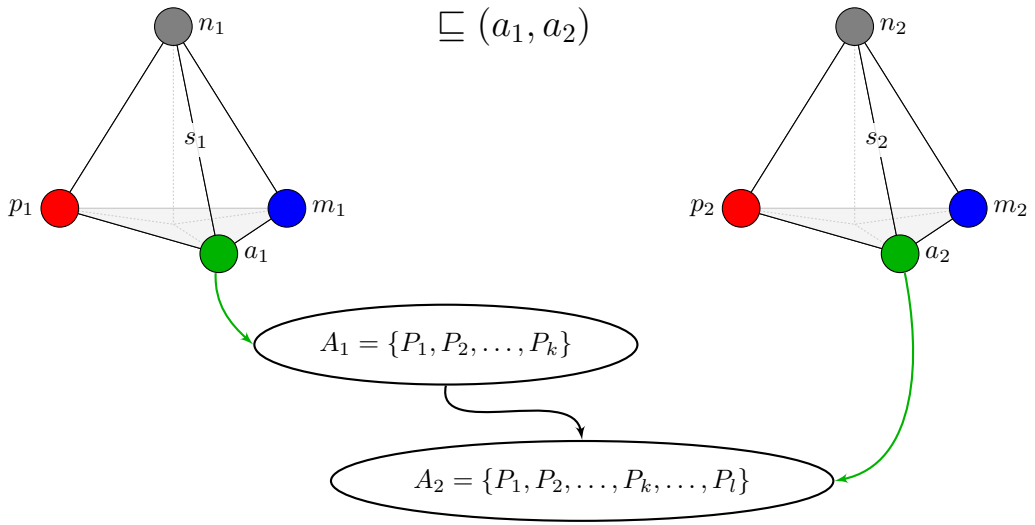
# Relations on sign components



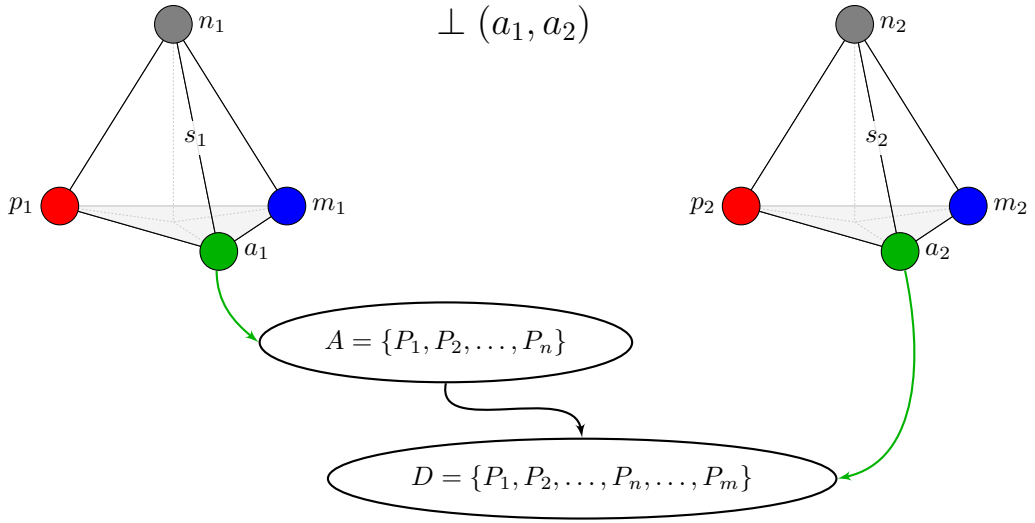

Script on significances.

# Relations on sign components

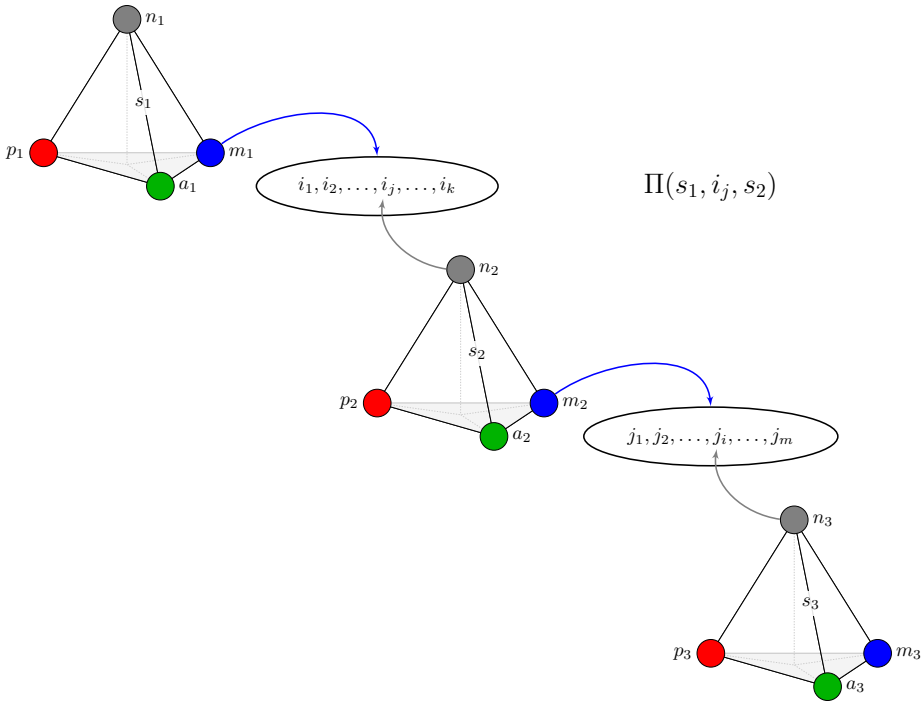
Subsumption of meanings:



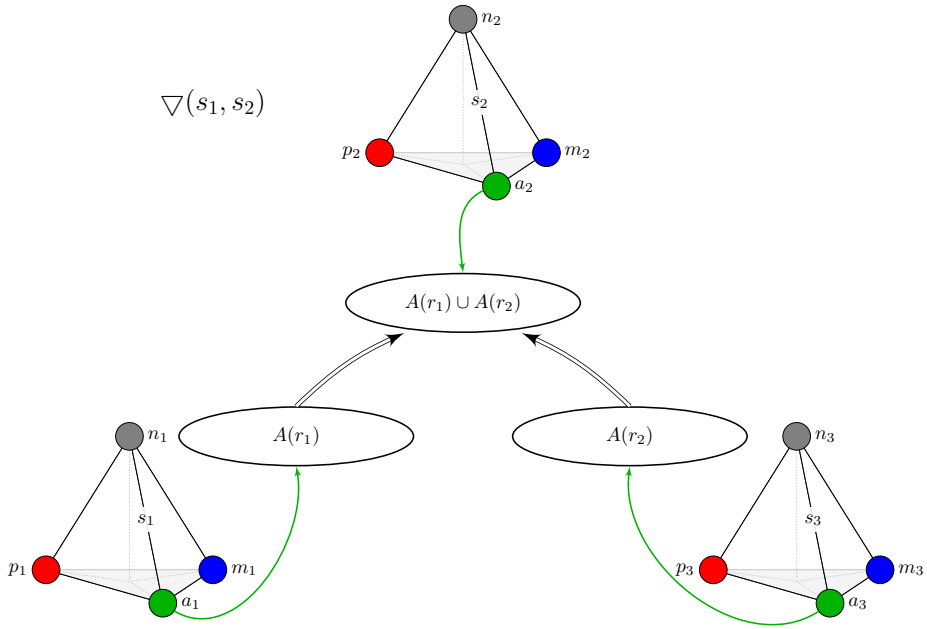

Opposition of meanings:



# Operations on sign components

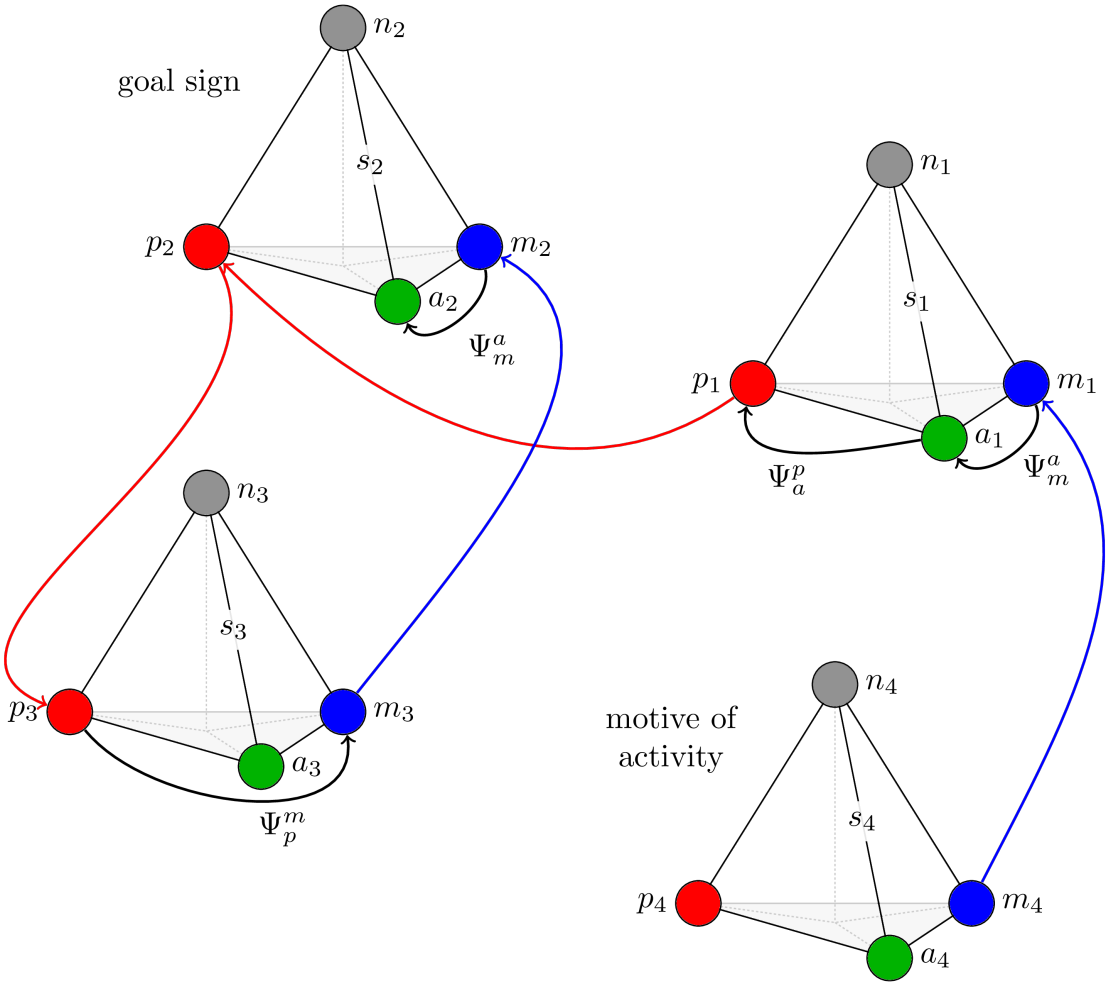



Operation of closure on significances.

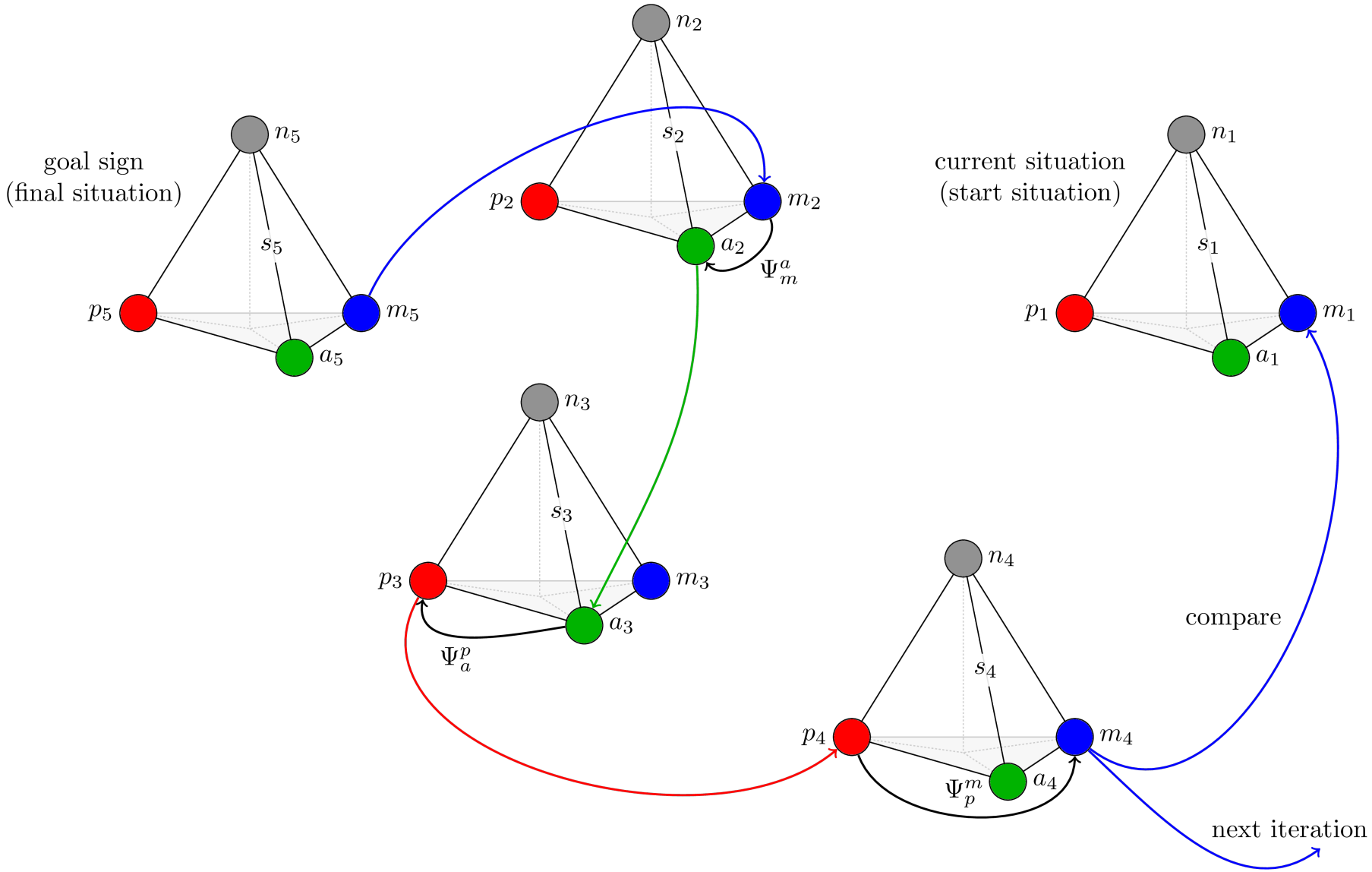



Operation of agglutination on meanings.

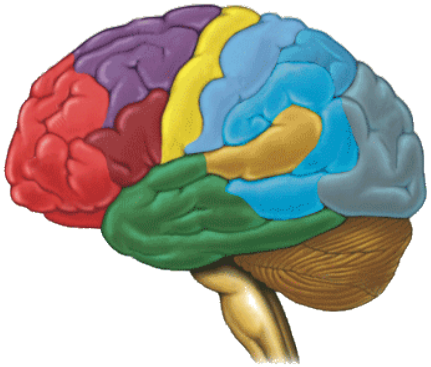
# Model of goal-setting function

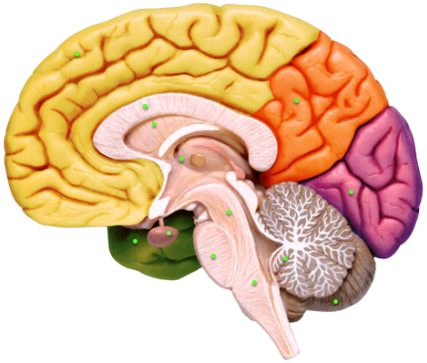


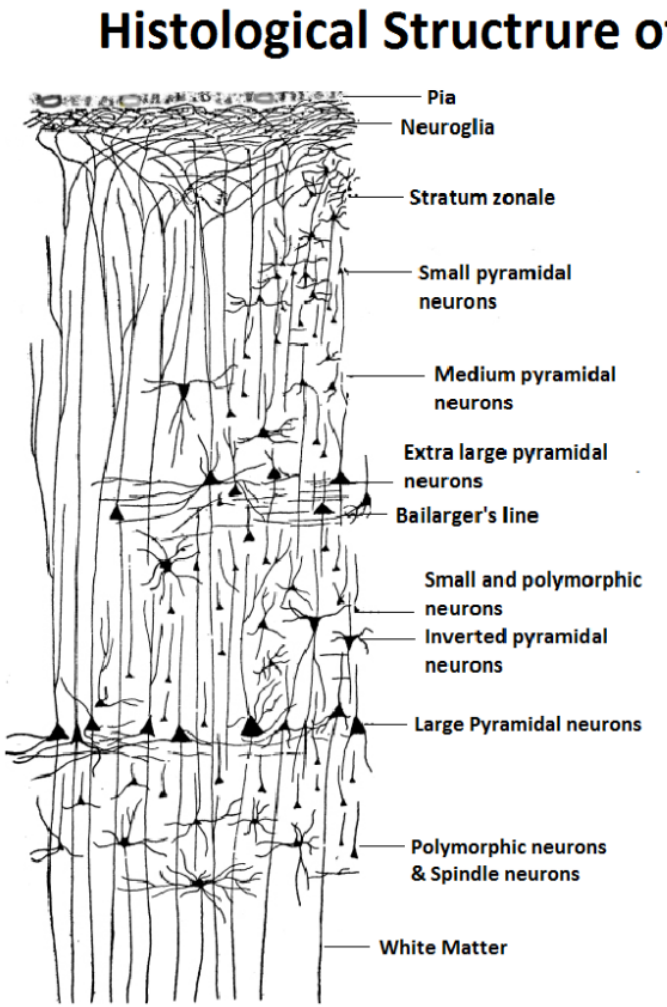
# Model of behavior planning function

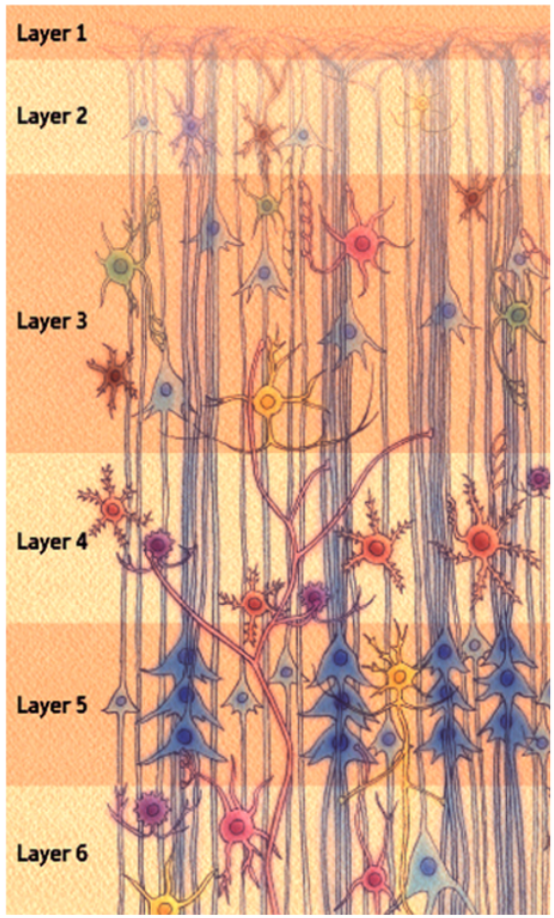


# Neural substrate





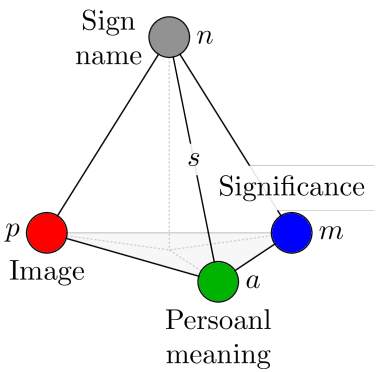


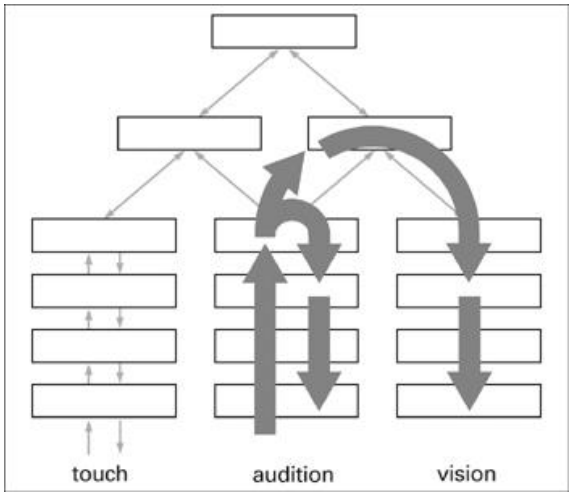





Anderson, John R. et al. "A central circuit of the mind". 2008.
George, Dileep and Jeff Hawkins. "Towards a mathematical theory of cortical micro-circuits". 2009.
Rockland, Kathleen S. "Five points on columns". 2010.
DeFelipe, Javier. "The neocortical column". 2012.

# Sign grounding assumptions

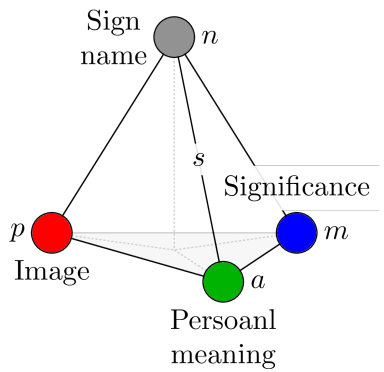


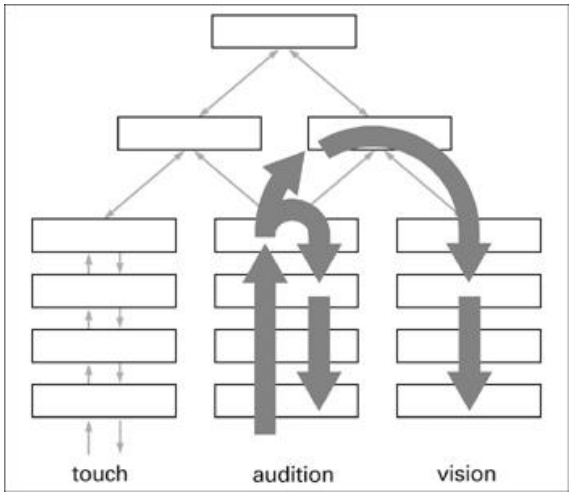




Hypothesis:

- neocortex consists of set of regions including set of columns, all regions are similar,
- columns are connected with lateral links,
- thalamus configures pattern sequences with inhibition and excitation processes.

# Sign grounding assumptions

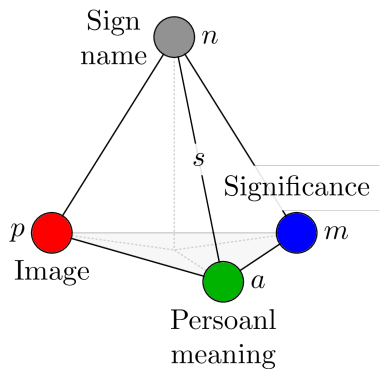


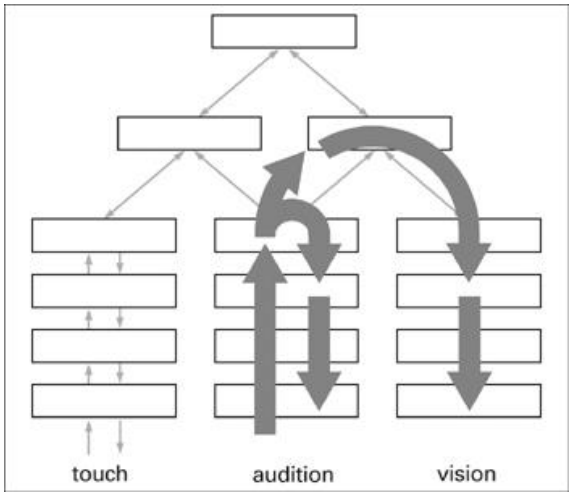




General features:

- all pattern sequences memorized in invariant form,
- all patterns are actualized associatively,
- all patterns are memorized in hierarchical form,
- feedback is used to predict input signal from low level.

# Sign grounding assumptions

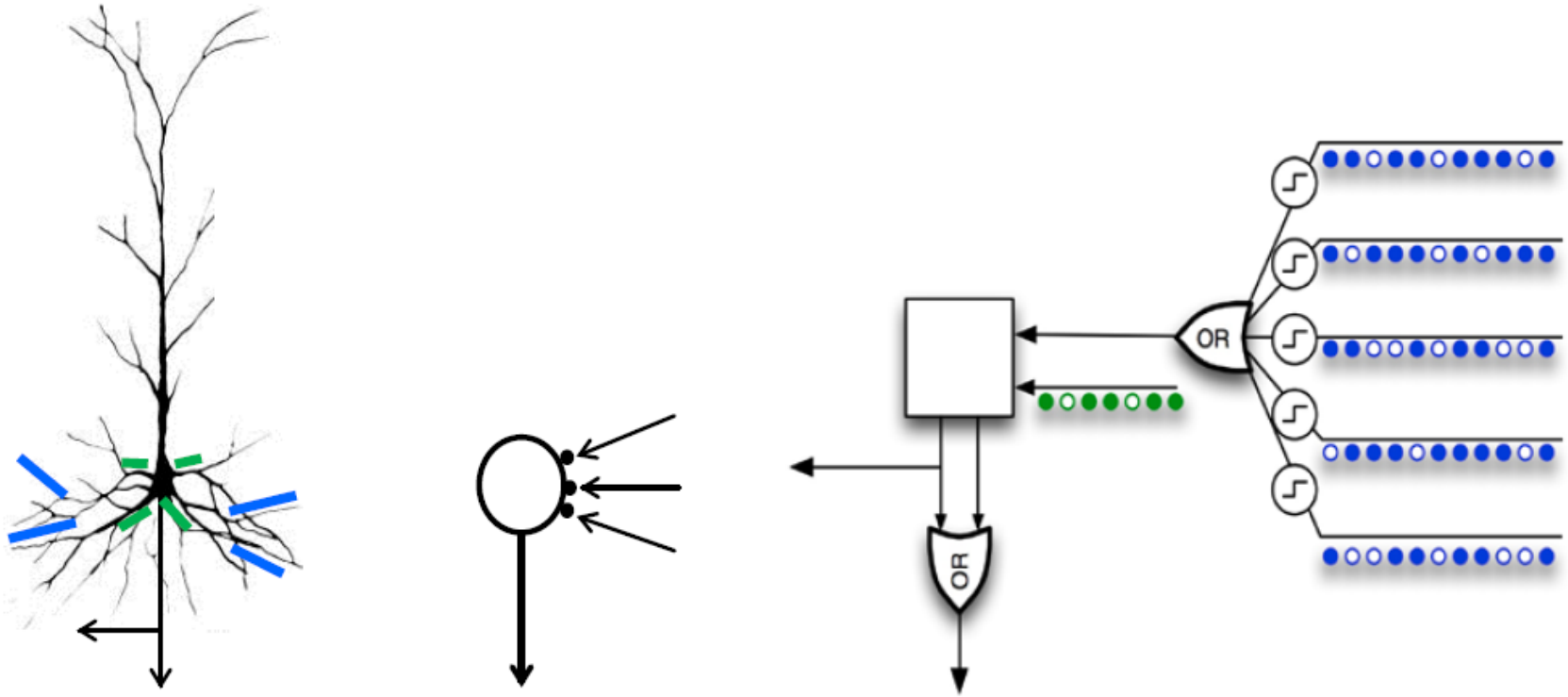



Simplifications:

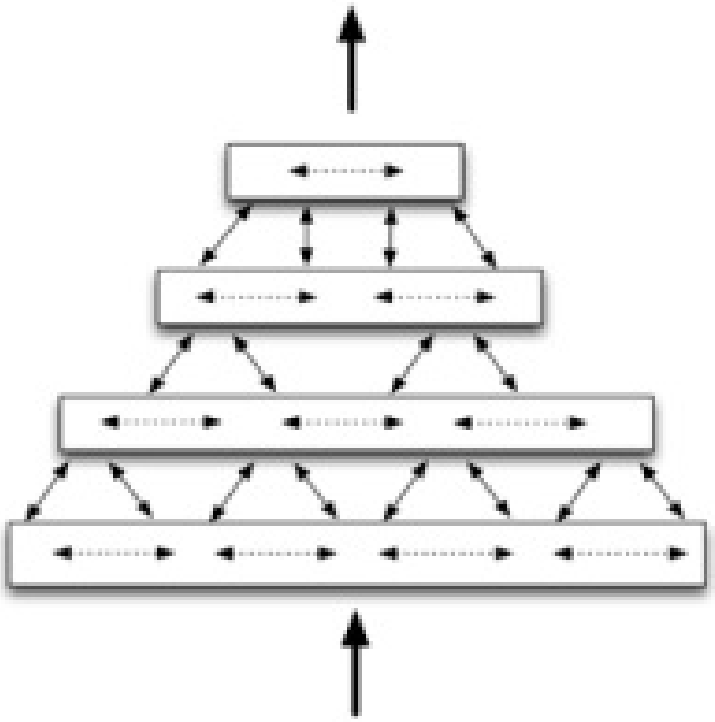
- tim is discretized,
- simple hierarchy with links between neighborhoods only,
- all events have the same duration in time,
- we use threshold model of decision process in the case of uncertainty,
- all unexpected signals are inhibited,
- we don't use motor part of feedback loop (meaning component).

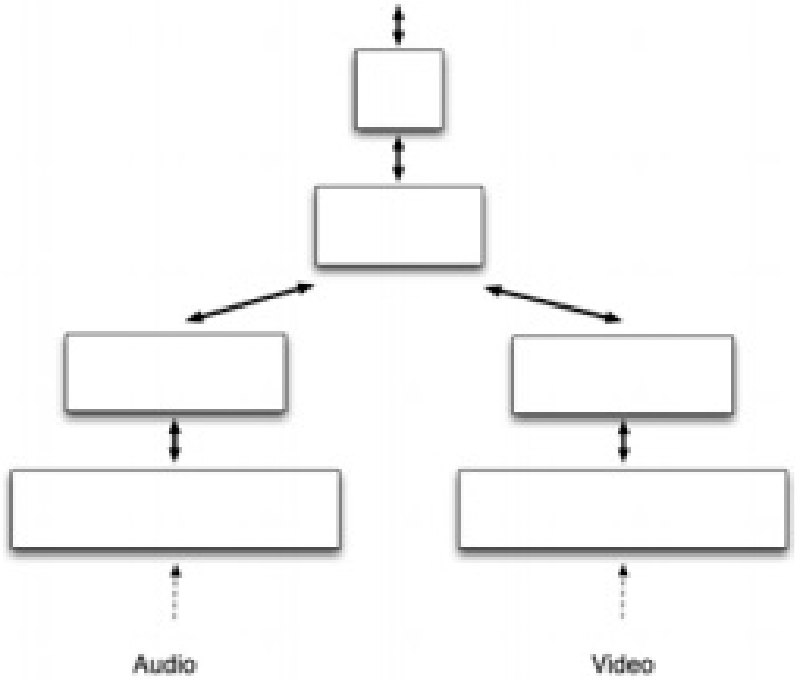
# Formal neuron model



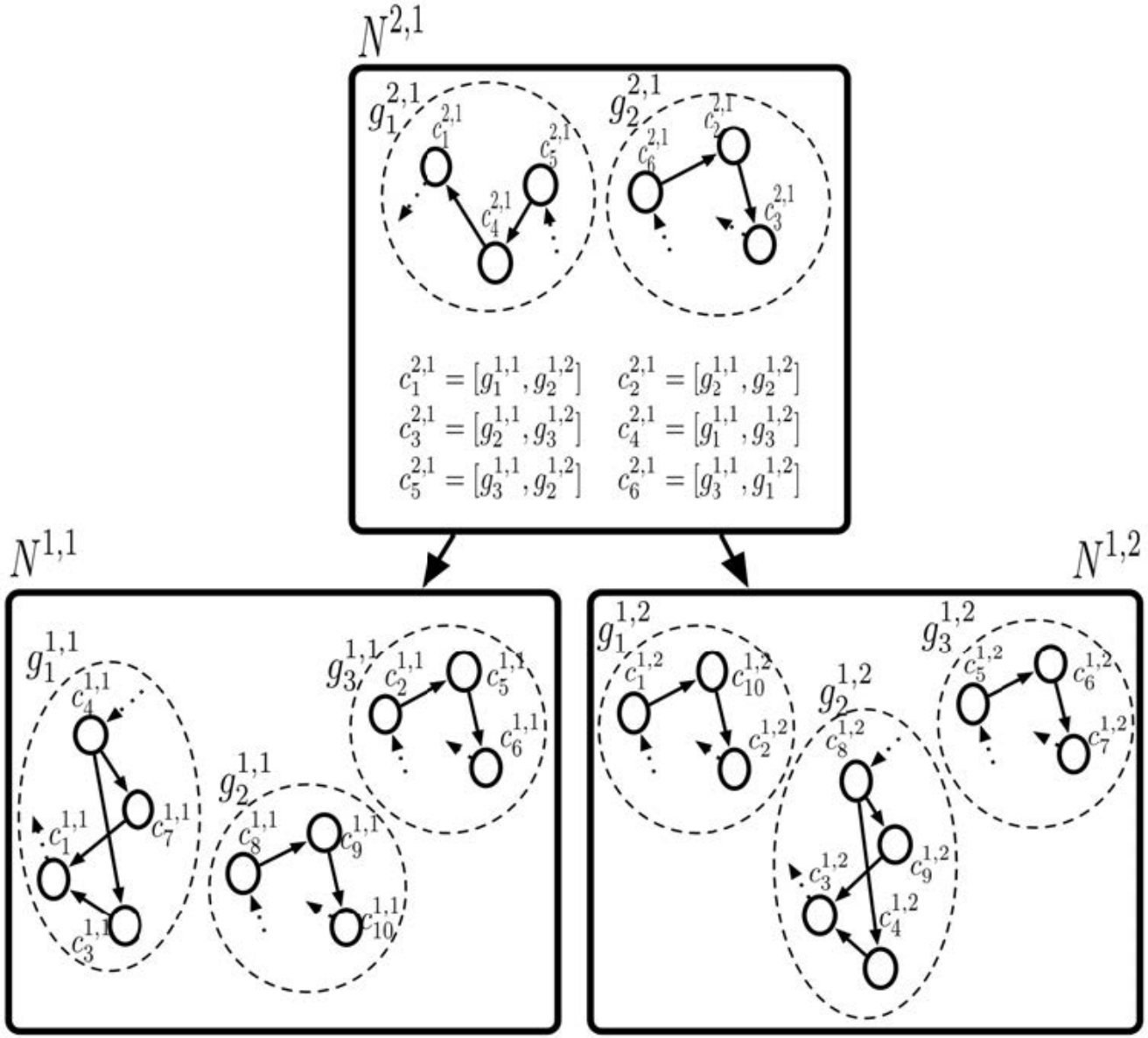

- A segment of proximal dendrite "— direct activation.
- Segments of distal dendrite "— lateral input and prediction state.

# Hierarchy of neuron ensembles

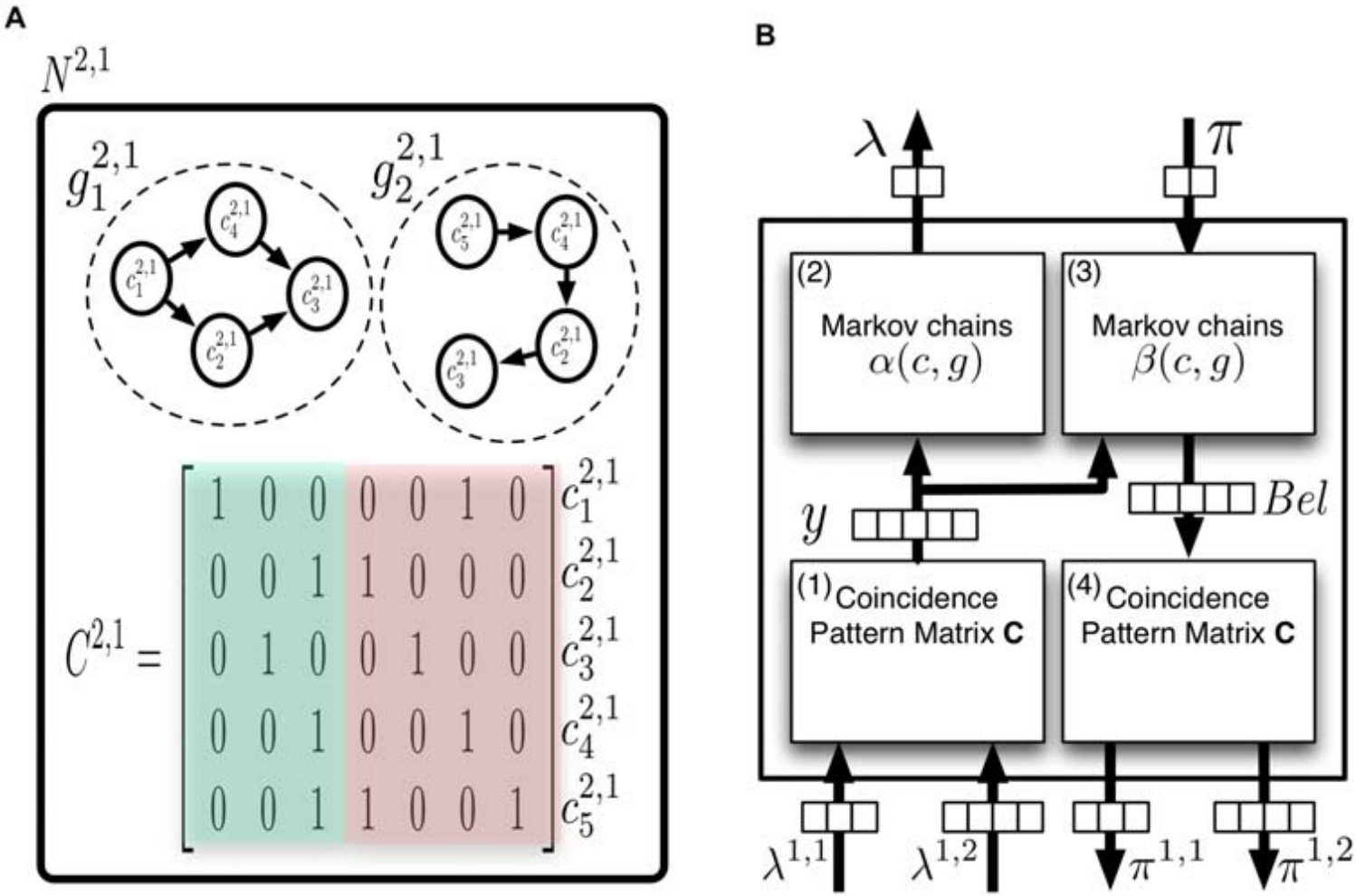




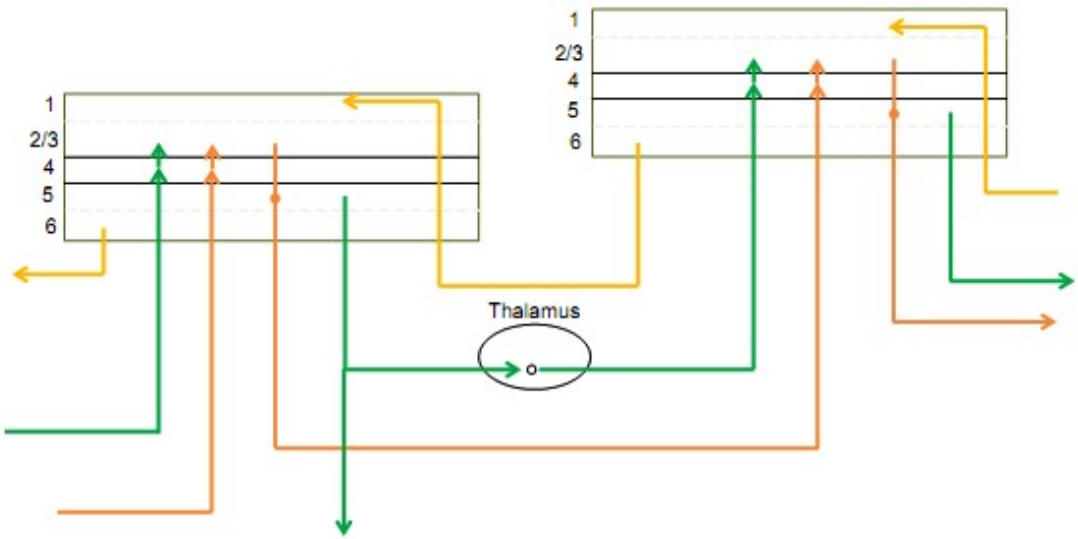
# Hierarchical model

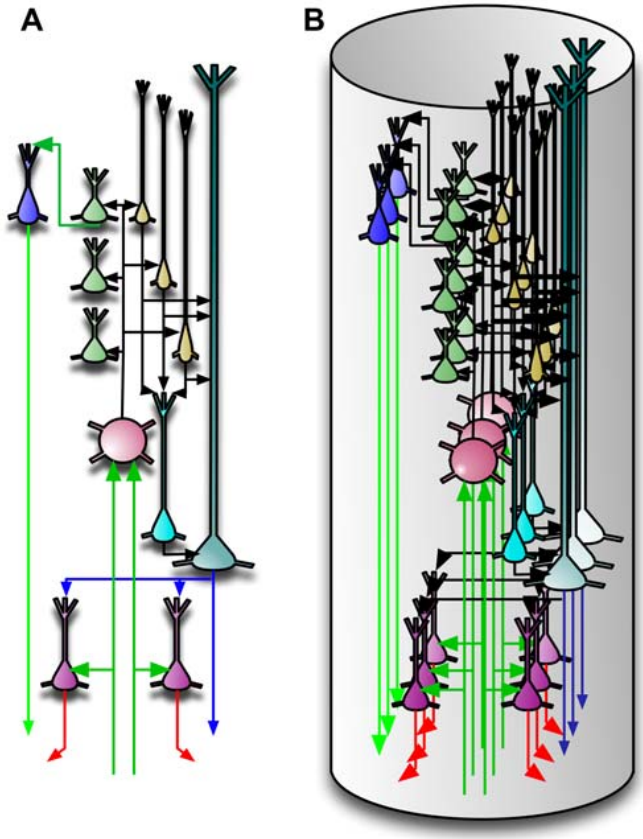


# Hierarchical model



# Layered organization

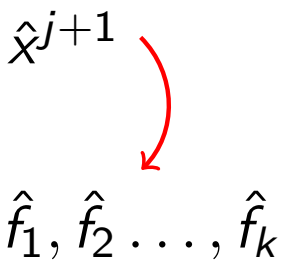


# Algorithm $\mathfrak{A}_{th}$ of sign component actualization

$\hat{f}_1, \hat{f}_2 \ldots, \hat{f}_k$

# Algorithm $\mathfrak{A}_{th}$ of sign component actualization



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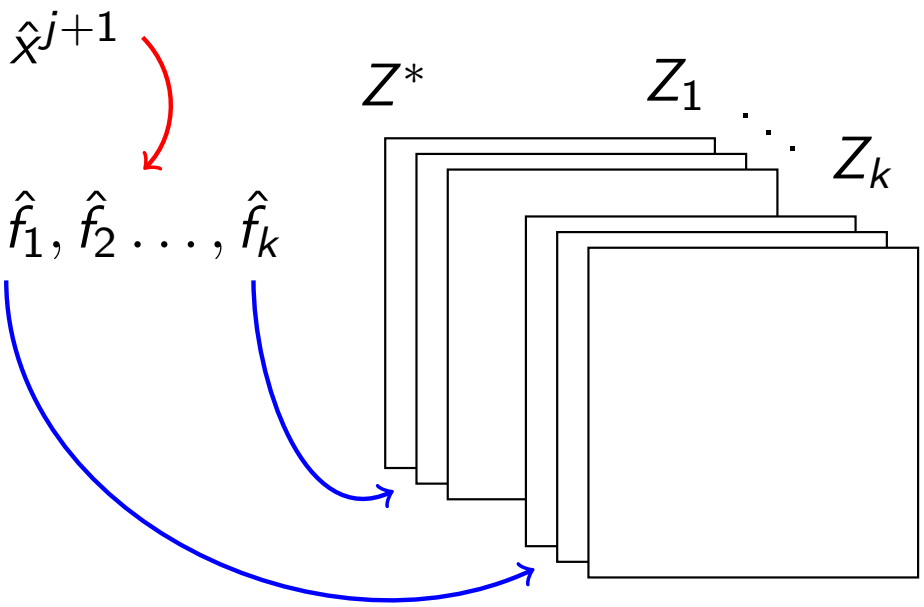

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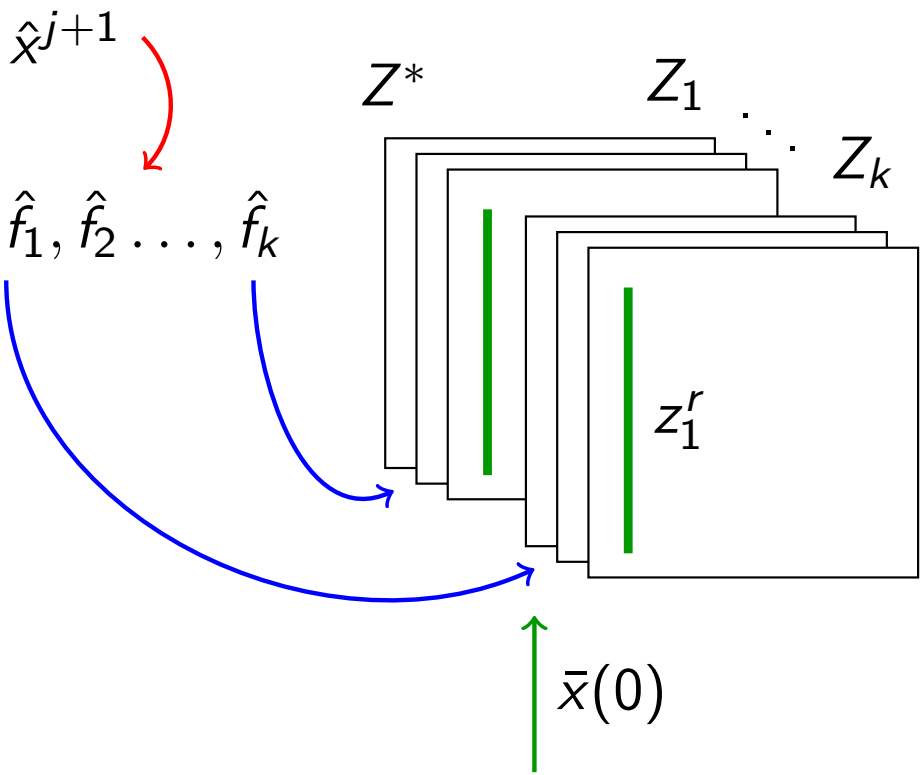

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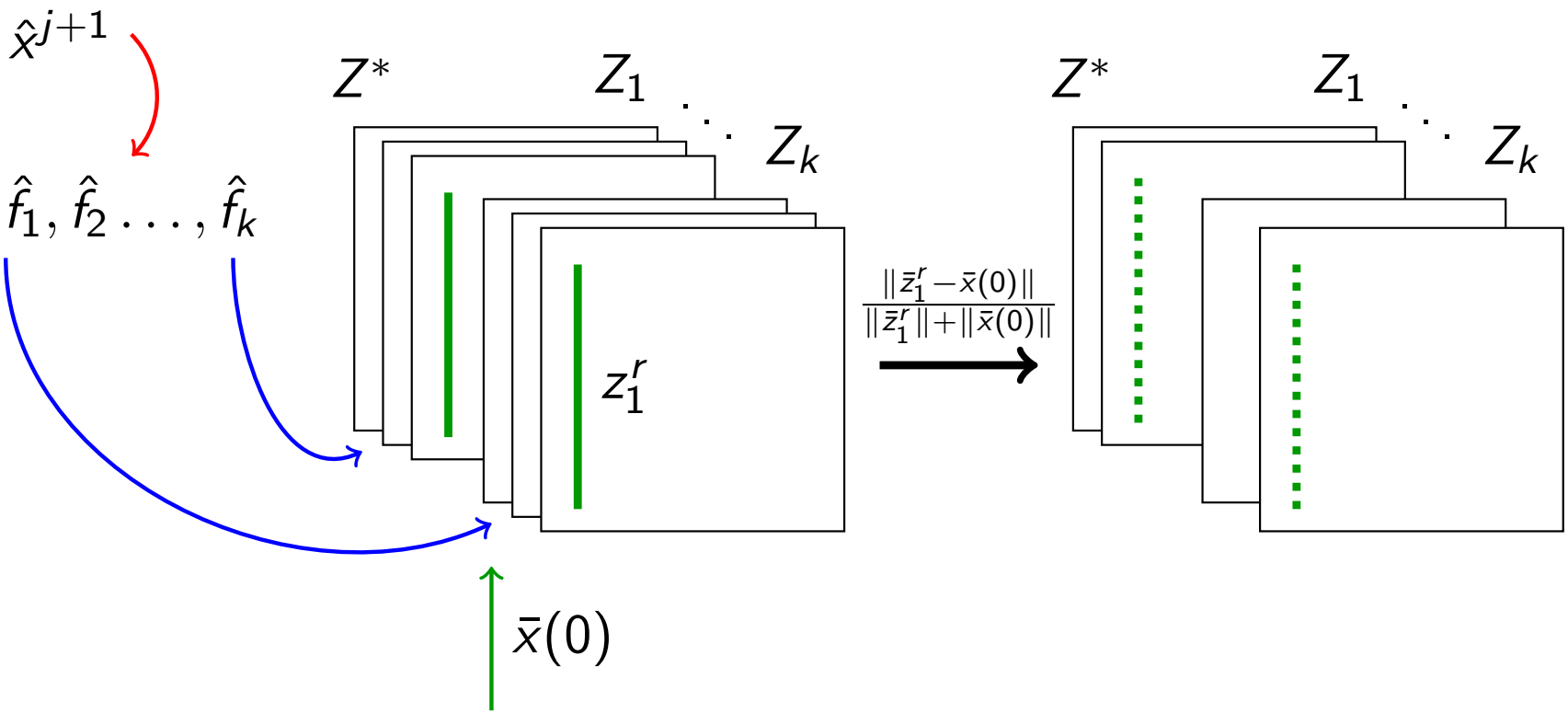

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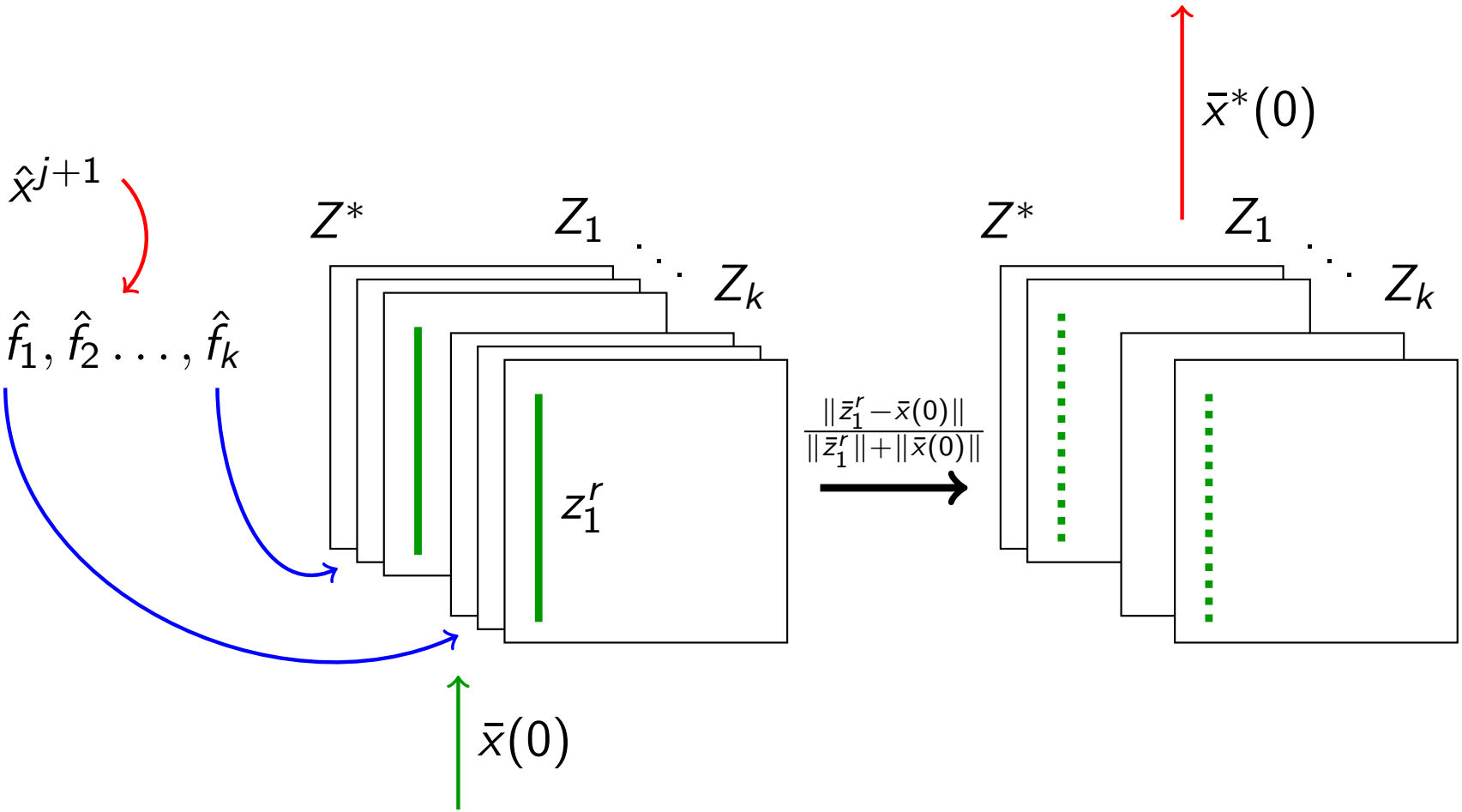

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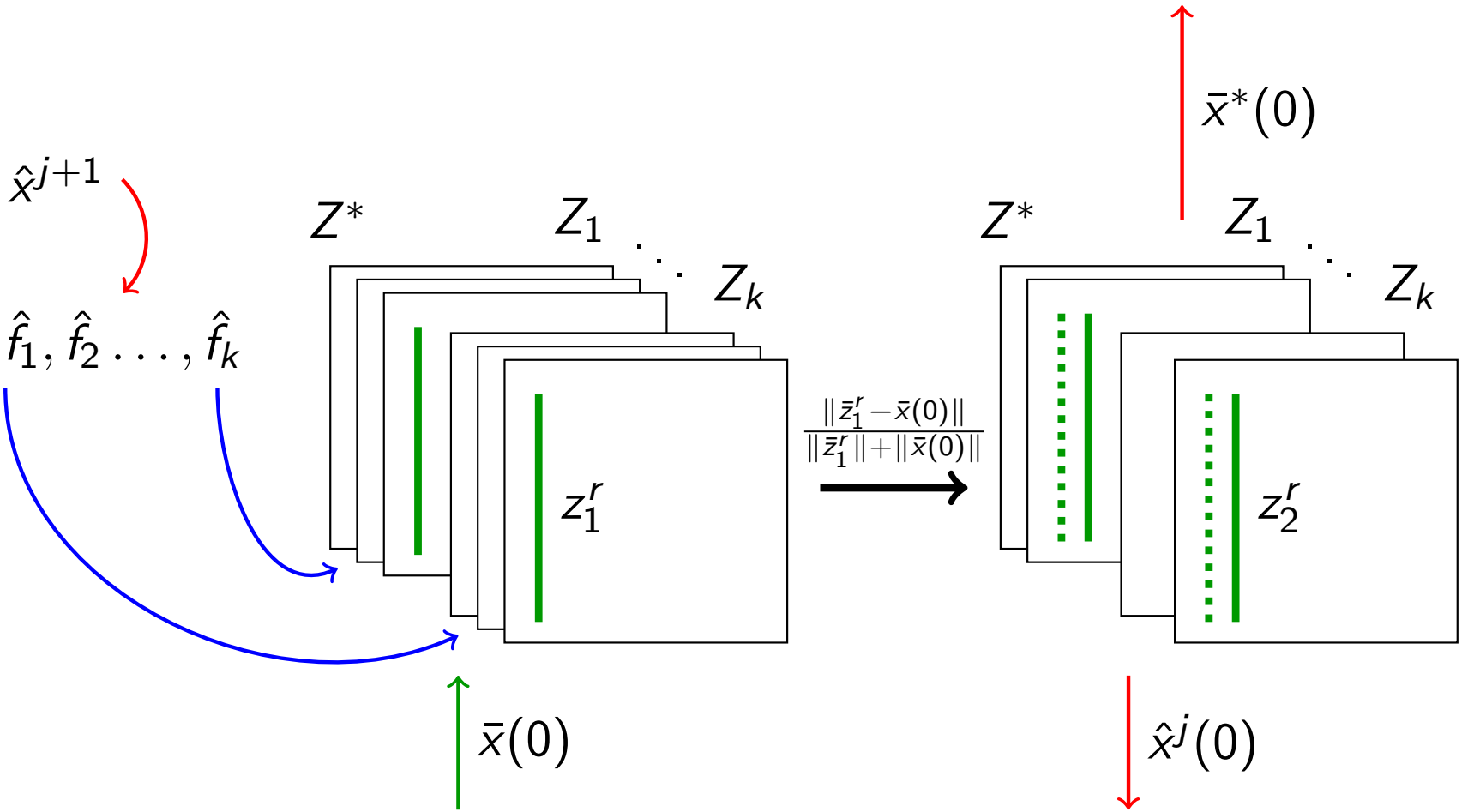
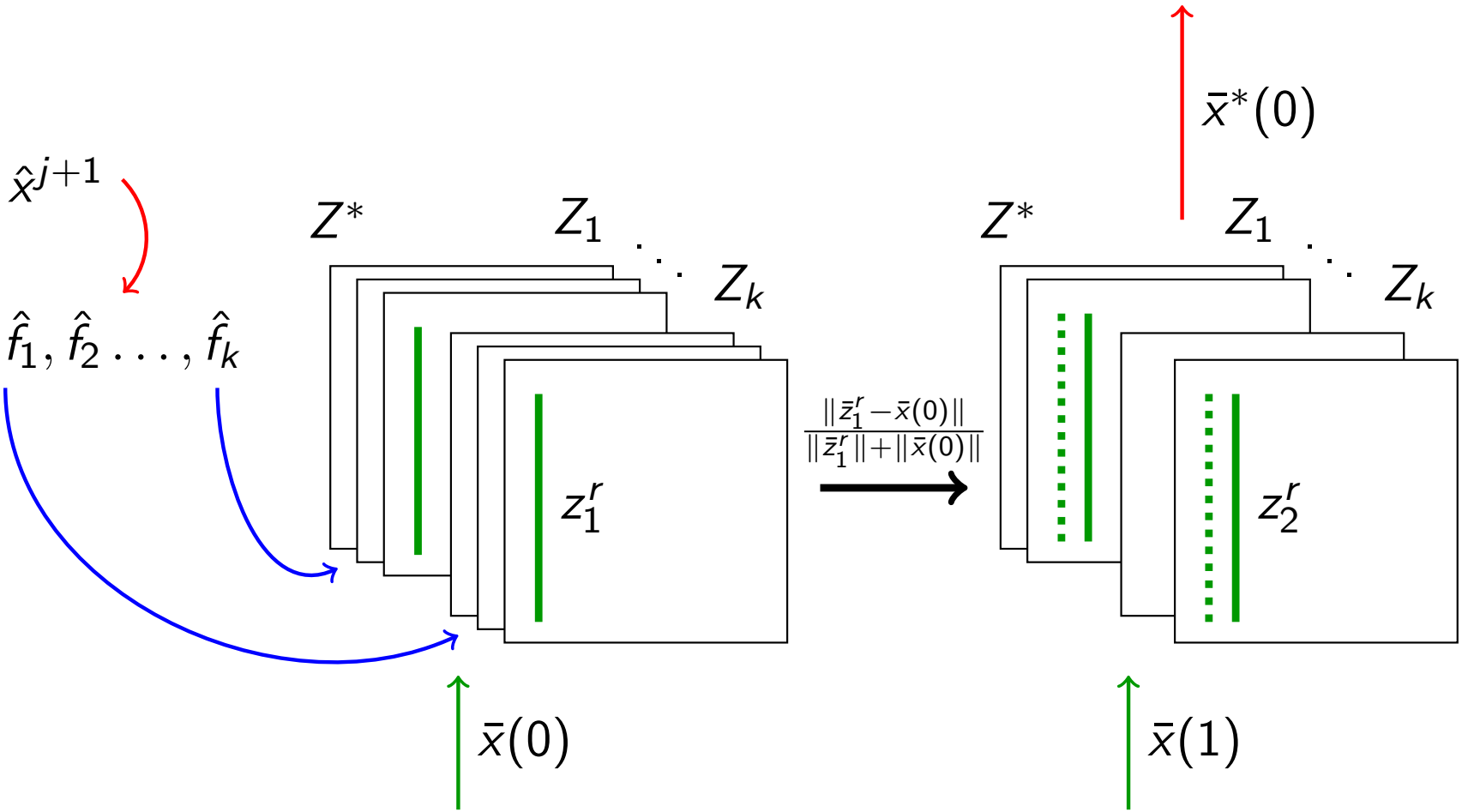
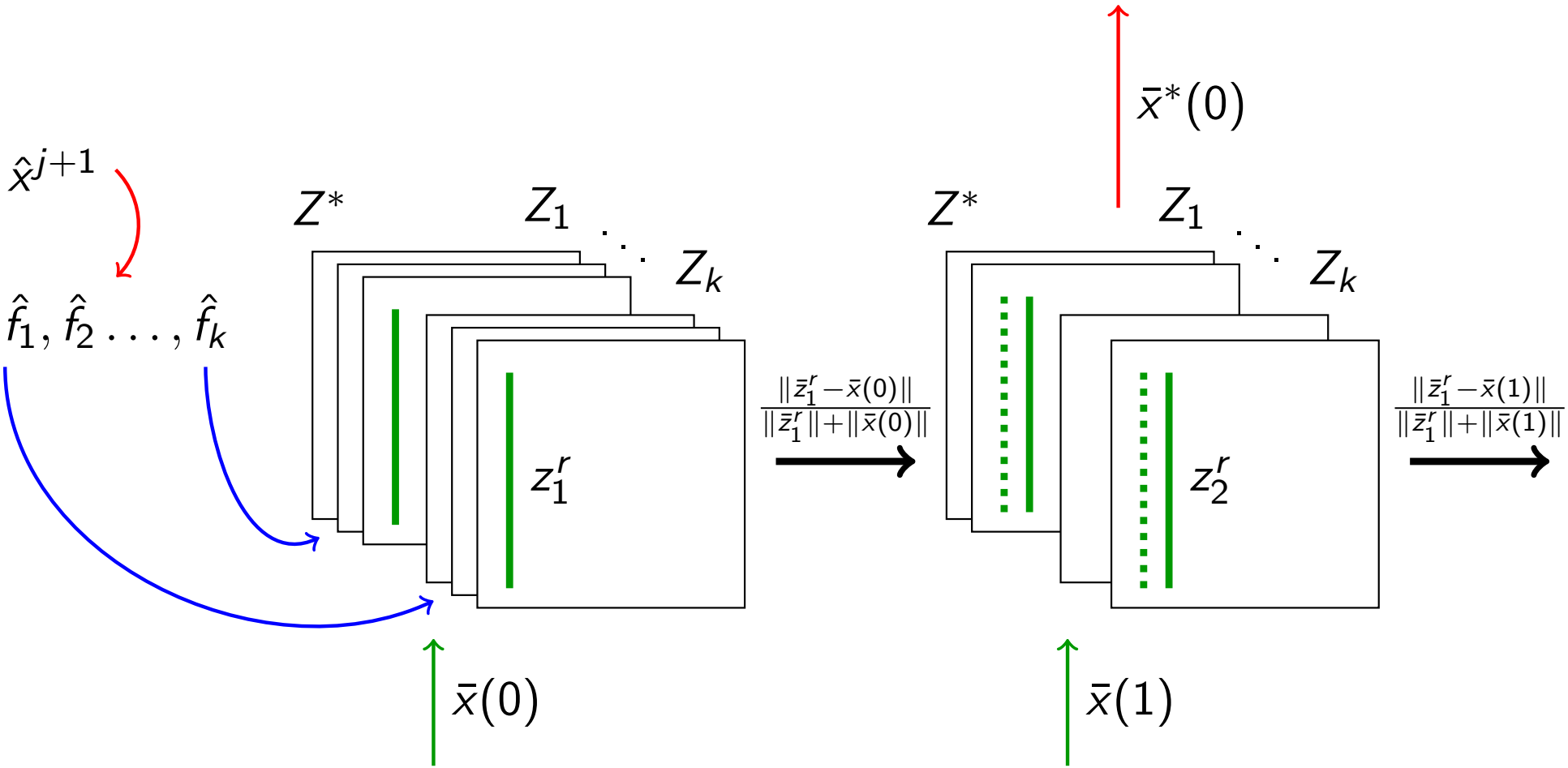


# Algorithm $\mathfrak{A}_{th}$ of sign component actualization



# Algorithm $\mathfrak{A}_{th}$ of sign component actualization



# Sign components

When learning process finished set of synapses defines both vertical connections between nodes and horizontal connections within a node.

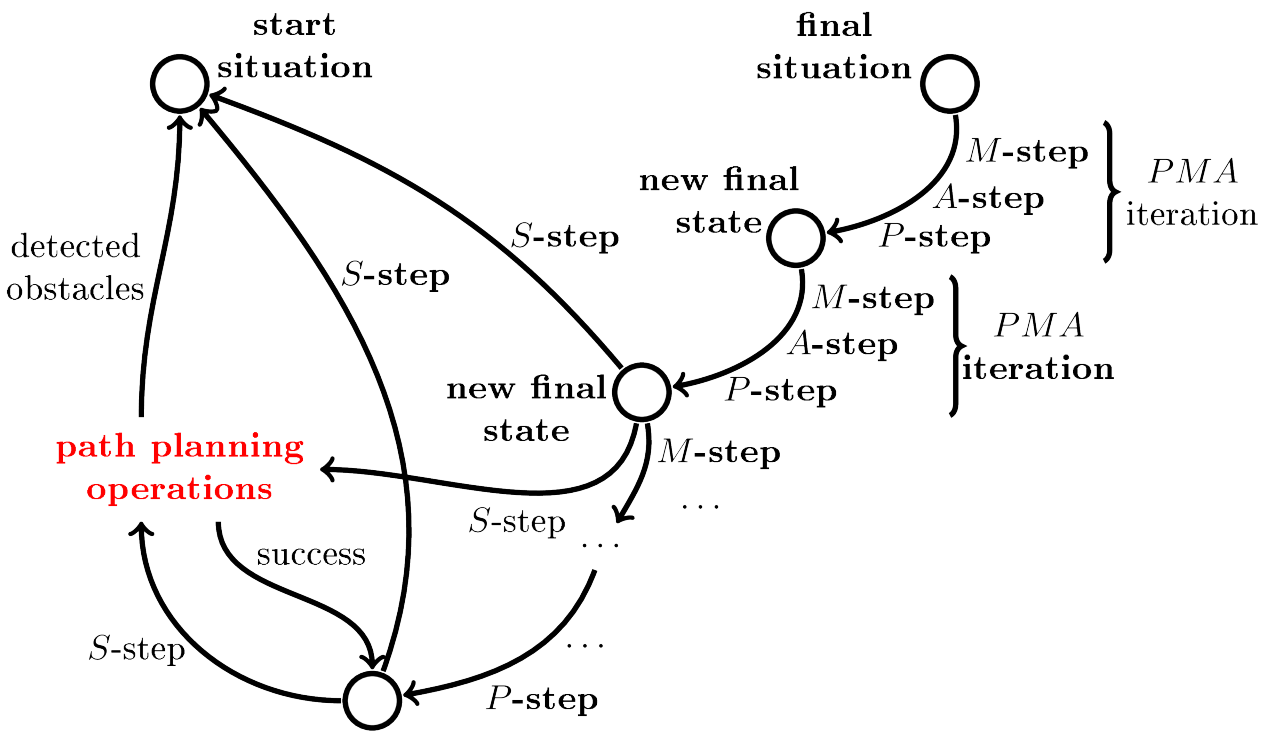
Each node is modeled with set of prediction matrices formed in a result of learning process within memory prediction framework.

$S \leftrightarrow F$ — naming process.

$$s = \langle p, m, a \rangle$$

$p$ – is the set of features included into prediction matrices of sign $s$,
$m$ – is the set of features which includes the sign $s$ into its matrices,
$a$ – the same as $m$ but includes personal embodied features.

# Behavior planning algorithm



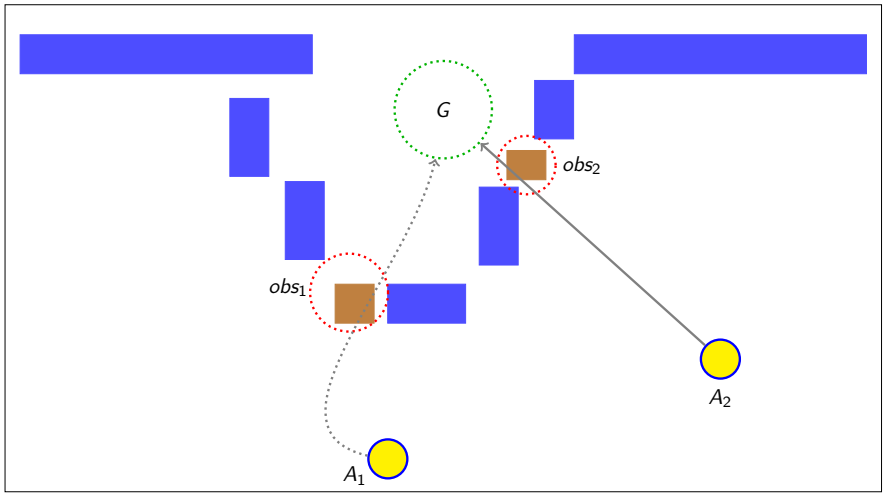

Planning starts from final situation and aims to meet start situation.

Main steps of algorithm (MAP iteration):

- *M-step* – search of relevant significances,
- *A-step* – choose a personal meaning from the set of personal meanings corresponding to the found significances,
- *P-step* – construct the new current situation using the set of features from the condition of performed action,
- *S-step* – send a message to other members of the coalition or perform the action corresponding to the chosen personal meaning or execute action hierarchy up to path planning operations.

Panov, Aleksandr I. and Konstantin S. Yakovlev. "Behavior and path planning for the coalition of cognitive robots in smart relocation tasks". 2016.

# Smart Relocation Tasks (SRT)




**Problem**

Goal area can not be achieved by some agents on their own (using standalone task and path planning methods)

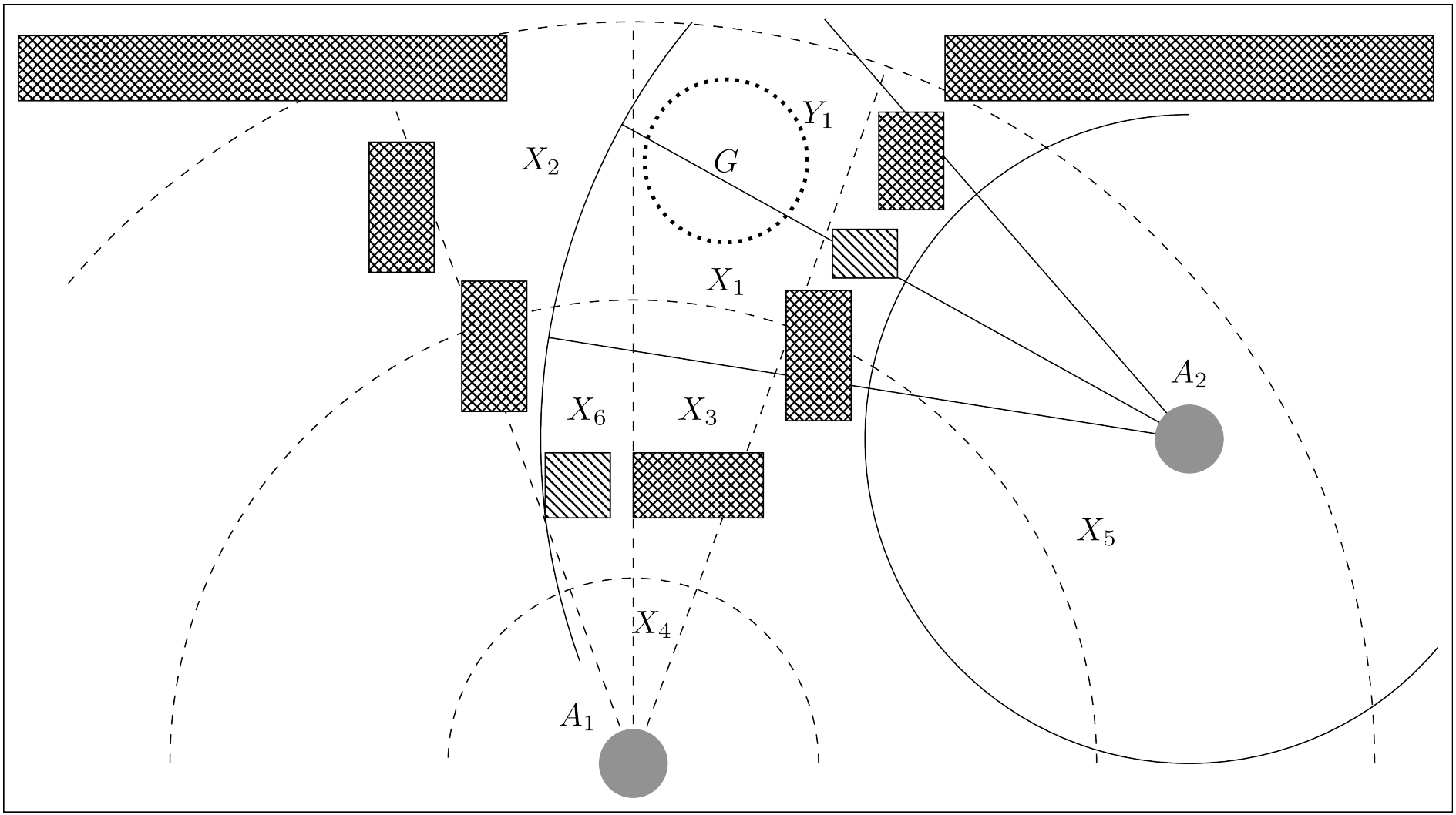
**Solution**

Agents must communicate and some agents must alter their "selfish" plans in order to construct coalition plan

3 levels of control:

- Transformable environment
- Different types of obstacles (some – can be destroyed)
- Agents with different capabilities (some agents can destroy obstacles, others – can not)
- Common spatial goal (ALL agents must reach this region in order goal to be achieved)

# Model task



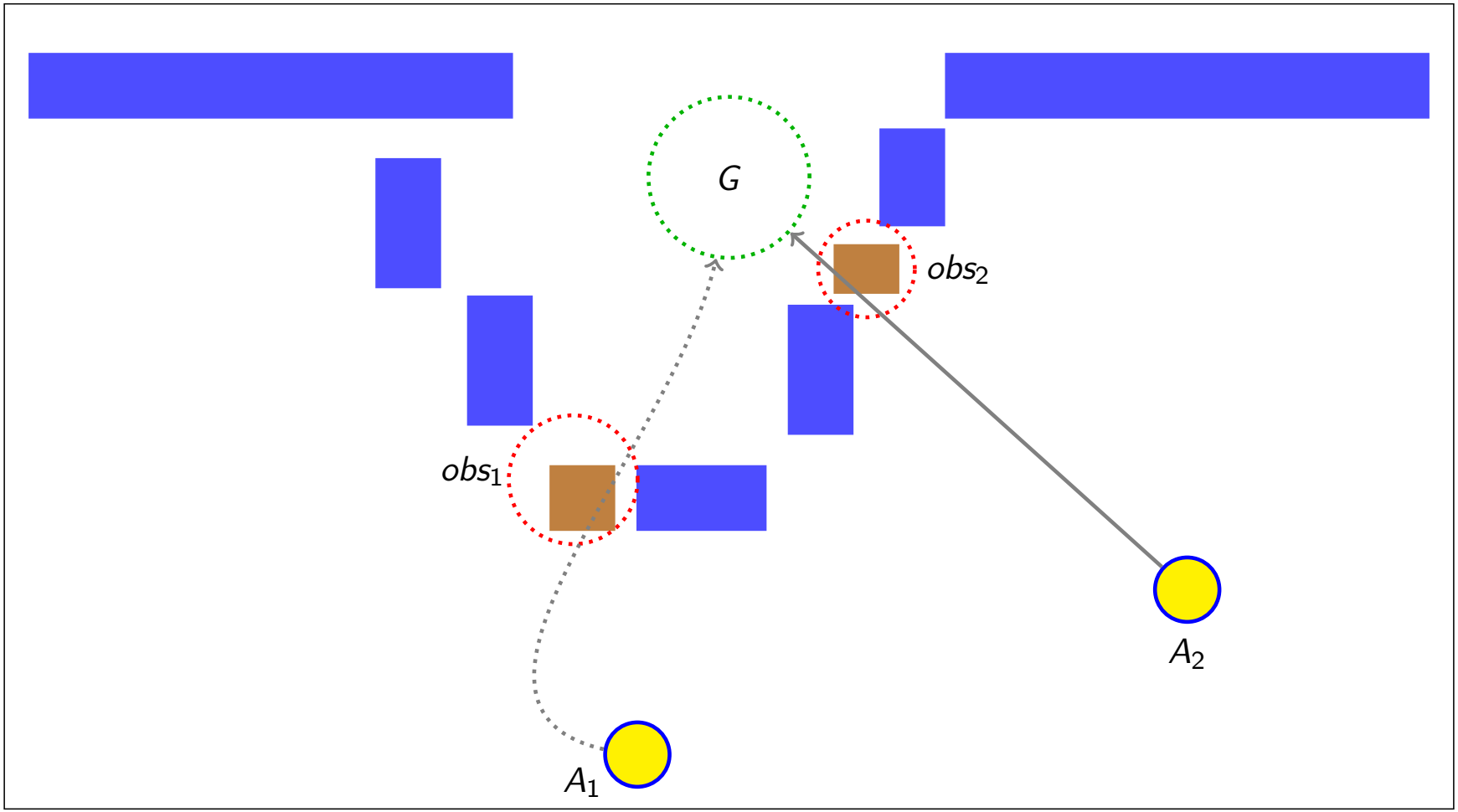
# Spatial knowledge representation

Relocation actions — signs $s_t$ (features $f_t$, $t$ — relocation type), with corresponding prediction matrices $Z_t$ consist of 3 columns:

$$z_1 = (l_x, I), z_2 = (l_y, d_u, E), z_3 = (l_y, I, t_v),$$

- $l_x$, $l_y$ — features represented category of distance in a spatial logic (e.g., "far", "closely" etc.),
- $d_u$ — features represented category of direction in a spatial logic (e.g., "left", "straight" etc.),
- $t_v$ — features represented category of time in temporal logic (e.g., "soon", "not soon" etc.),
- $I$ — feature of agent presence,
- $E$ — feature of obstacle absence.

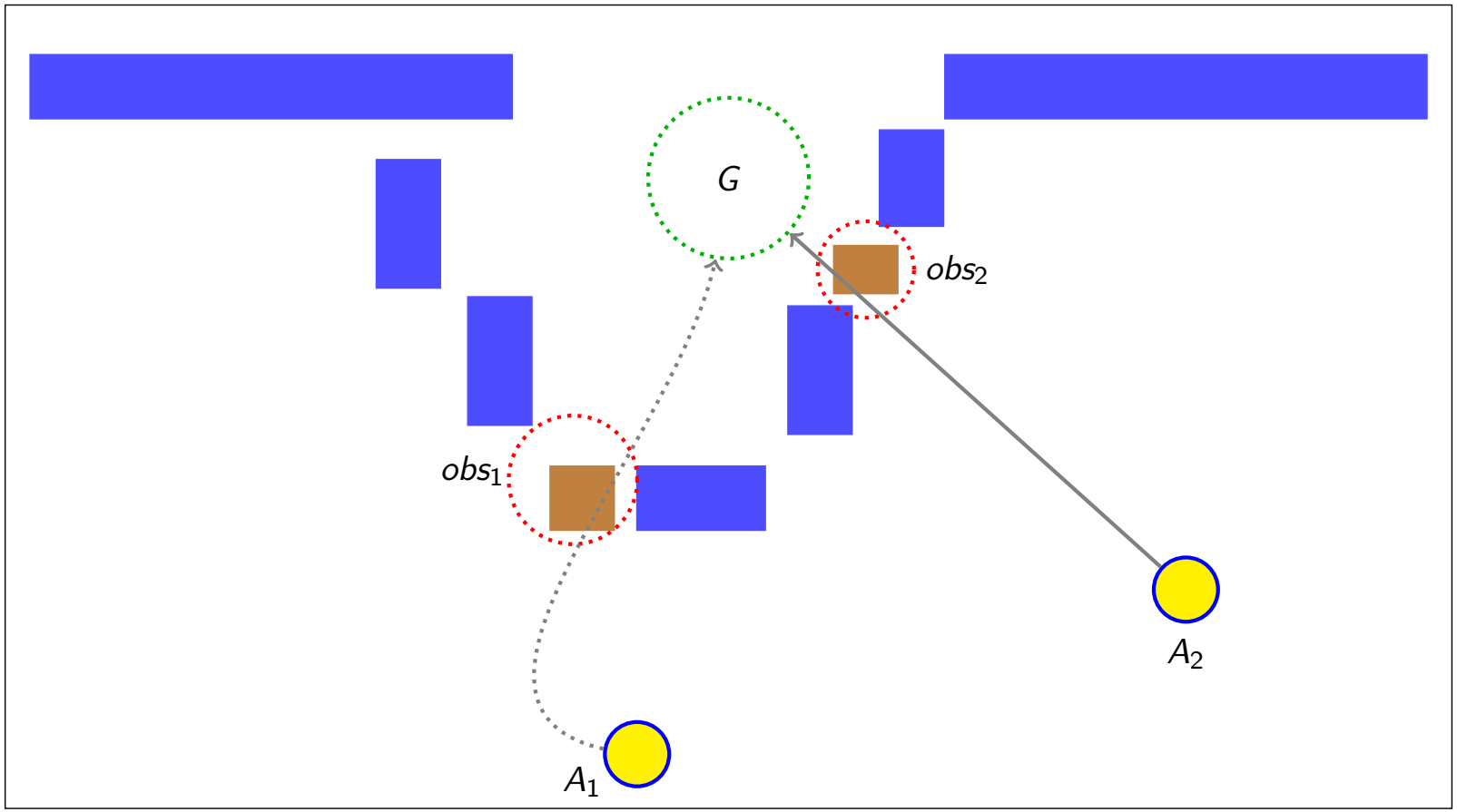
# Model task



# Interaction with Behavior planning

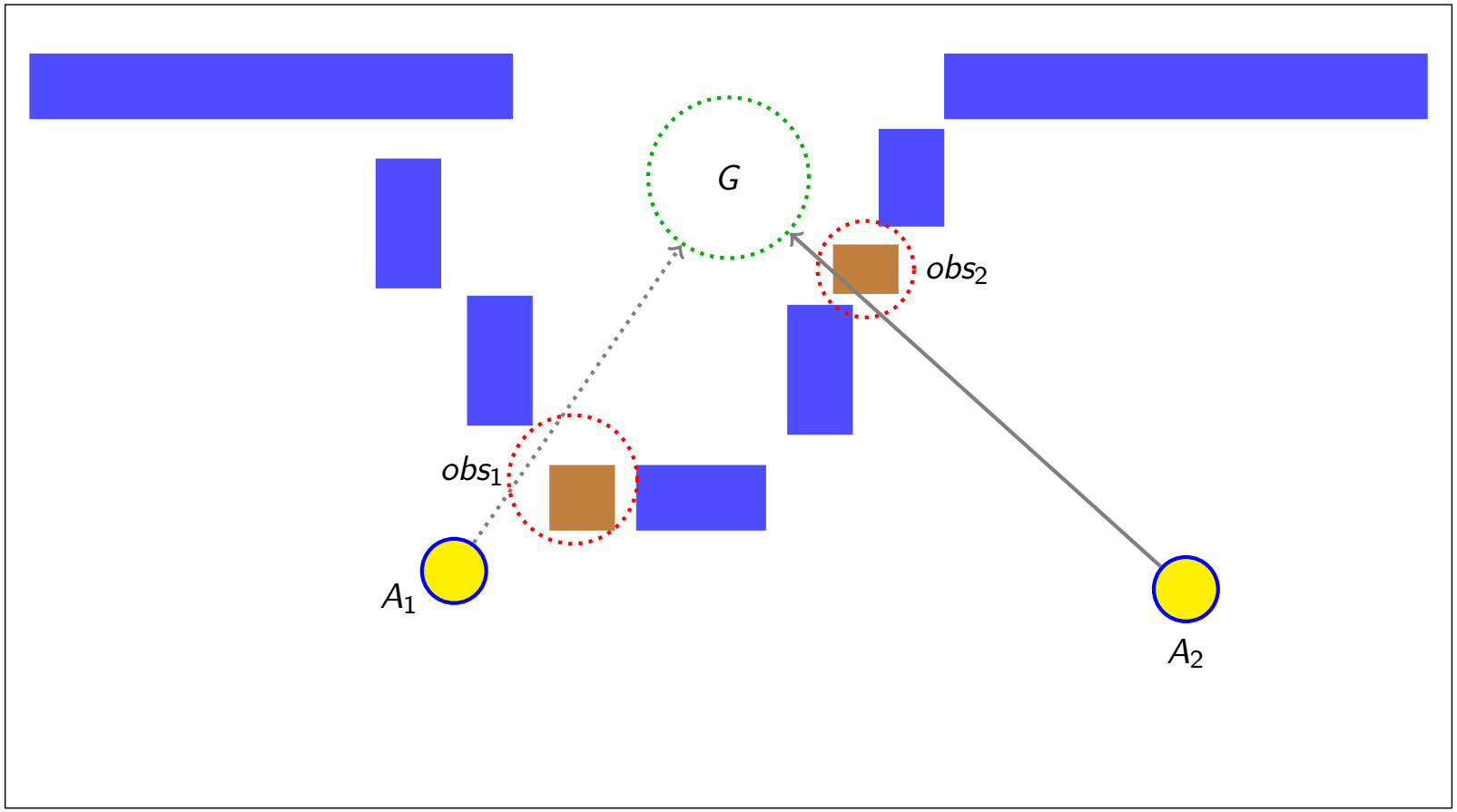
1. Non-angle-constrained path can not be found
   - It takes a while to come to that
   - Identify blocking obstacle
   - Pass id (or coordinates) of that obstacle to upper level of control
     - On upper level: messaging for help, altering the coalition plan
2. Non-angle-constrained path can is found but angle-constrained is not
   - Agent can not reach goal area under current constraints (time, speed etc.)
   - Inform upper level of control and ask for a task update (setting new time constraints for example)

# Case study



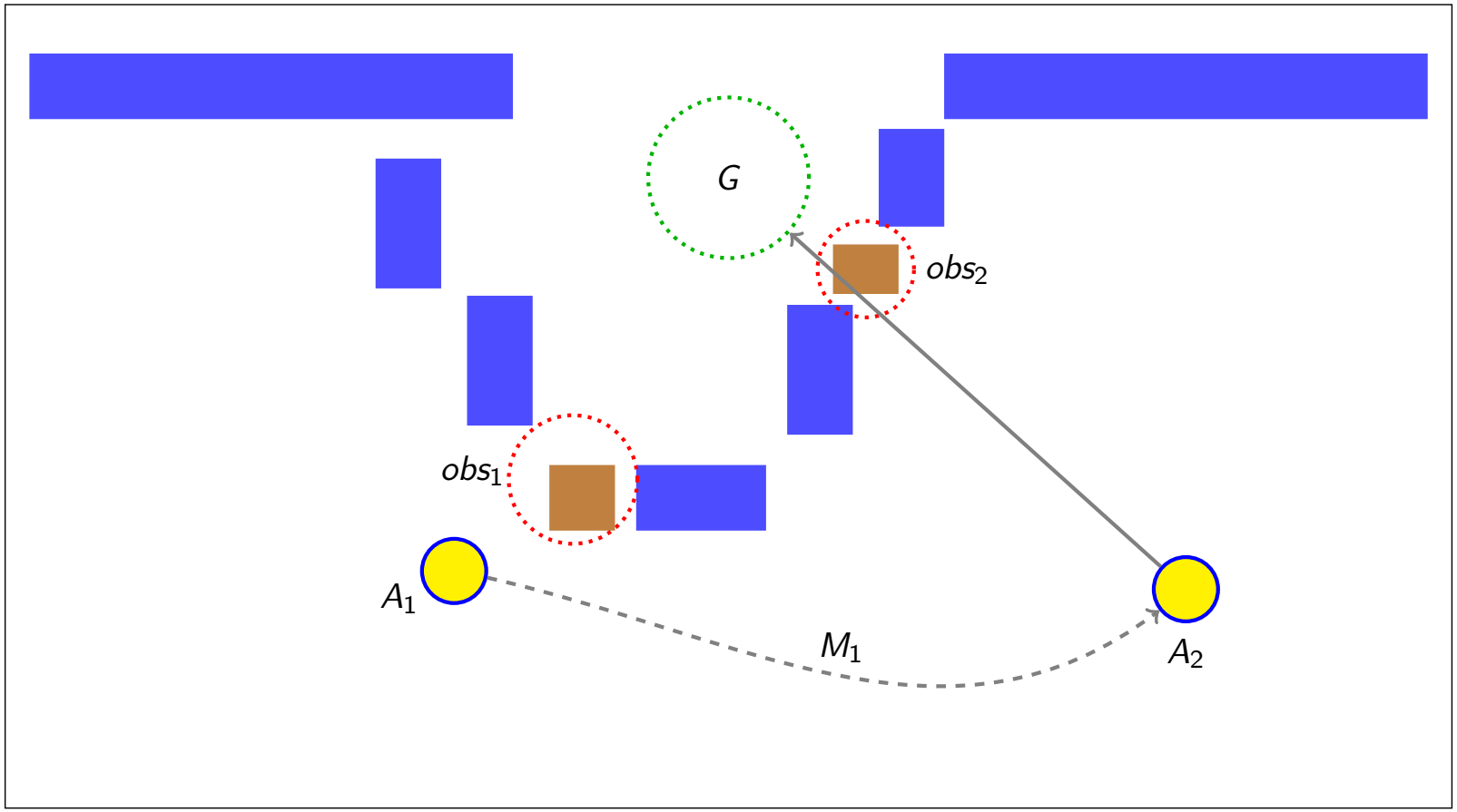

Activated signs for agent $A_1$: "place $X_6$", "far", "move 1" $\rightarrow$ path planning operations.

# Case study



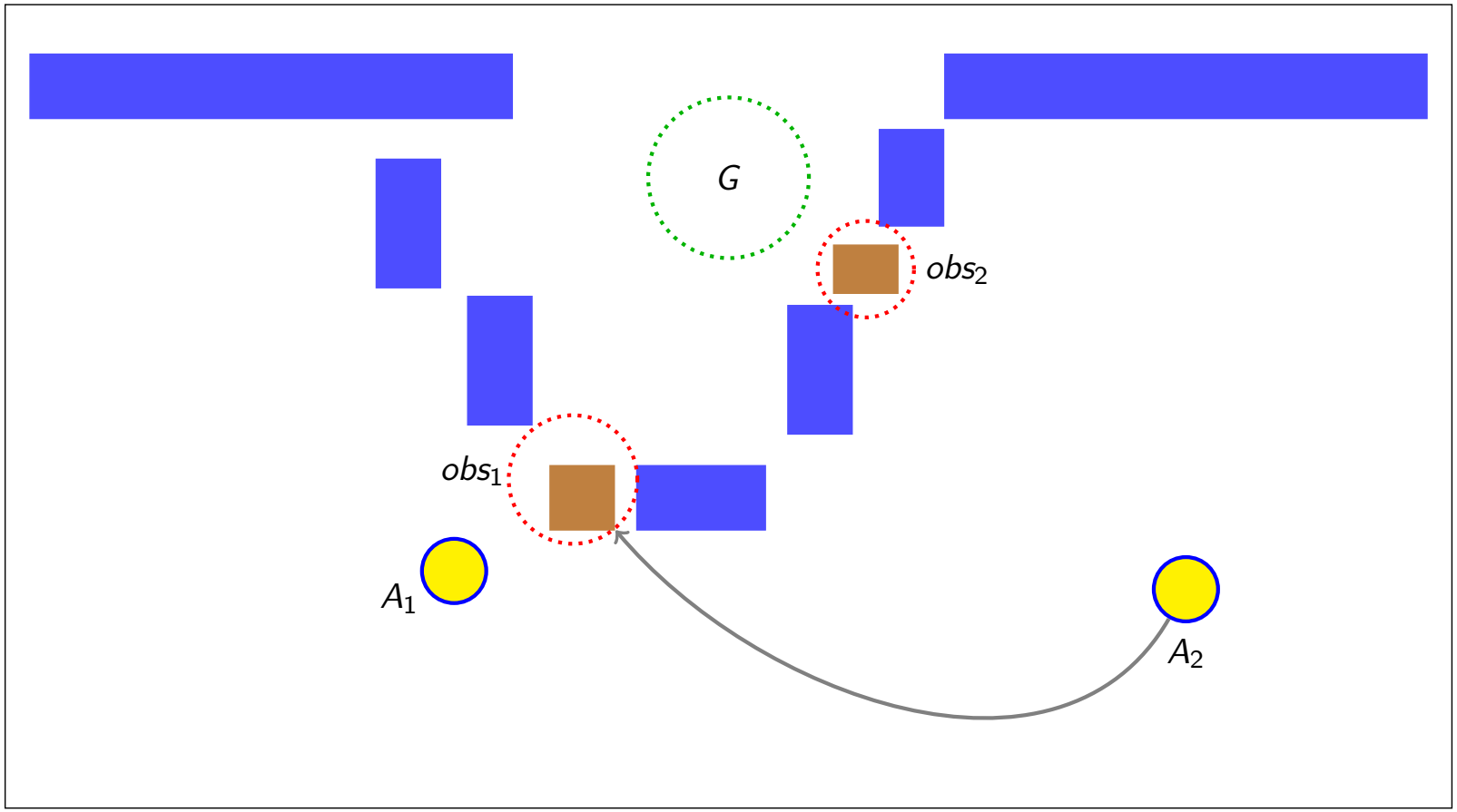

Activated signs for agent $A_1$: "obstacle 1", "near", "place $X_6$".

# Case study



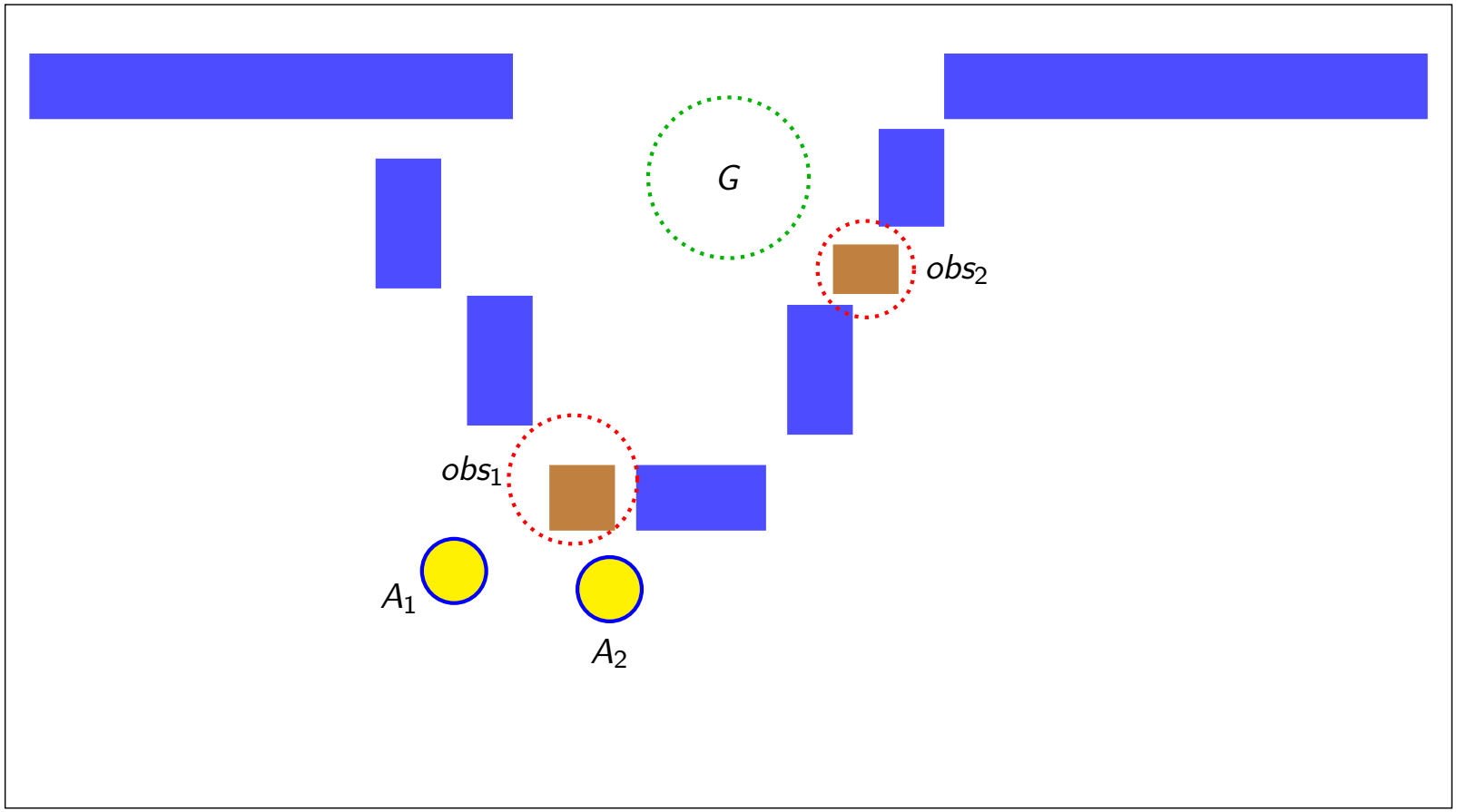

Activated signs for agent $A_1$: "send message", "agent $A_2$".

# Case study



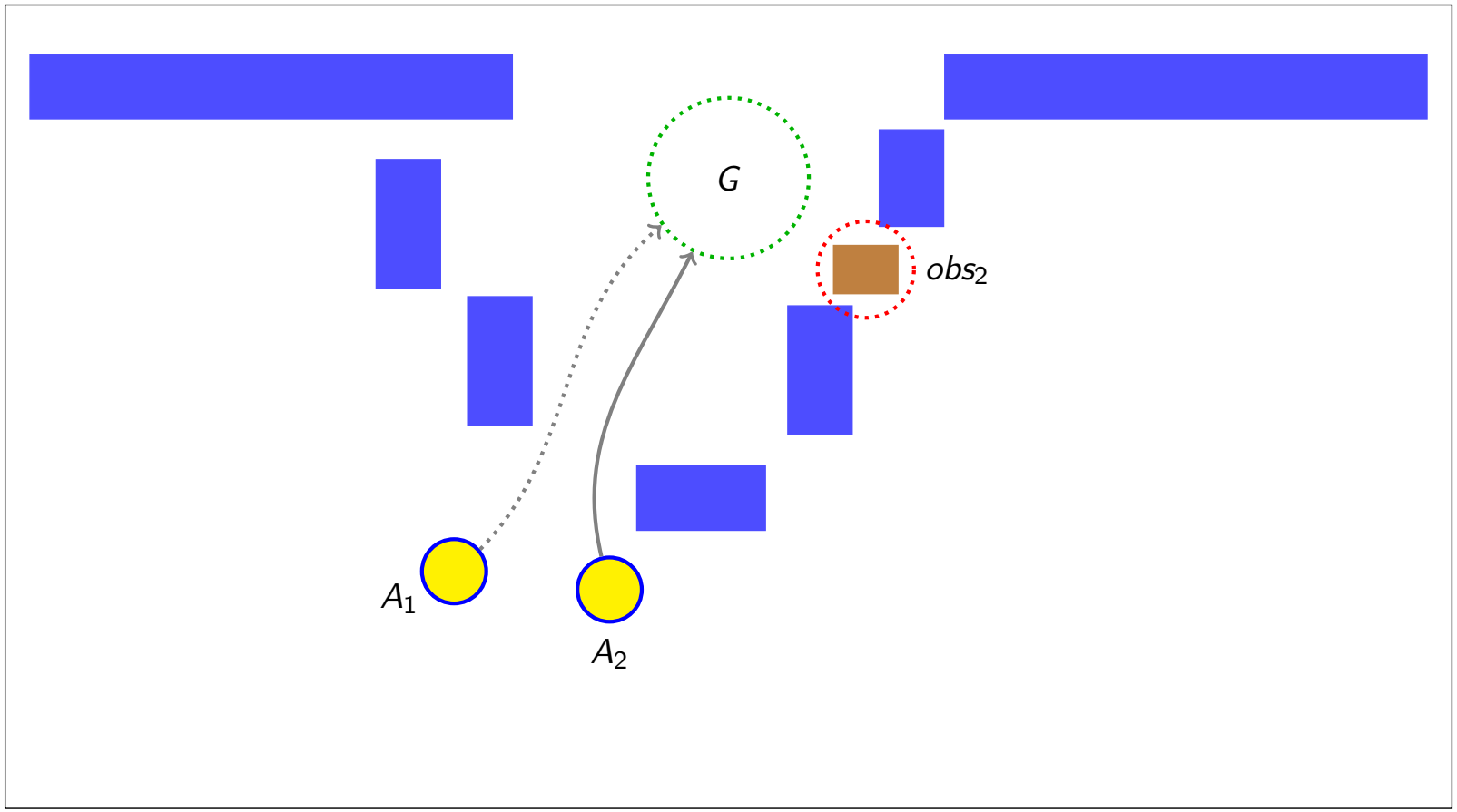

Activated signs for agent $A_2$: "place $Y_3$", "far", "move 2" $\rightarrow$ path planning operations.

# Case study



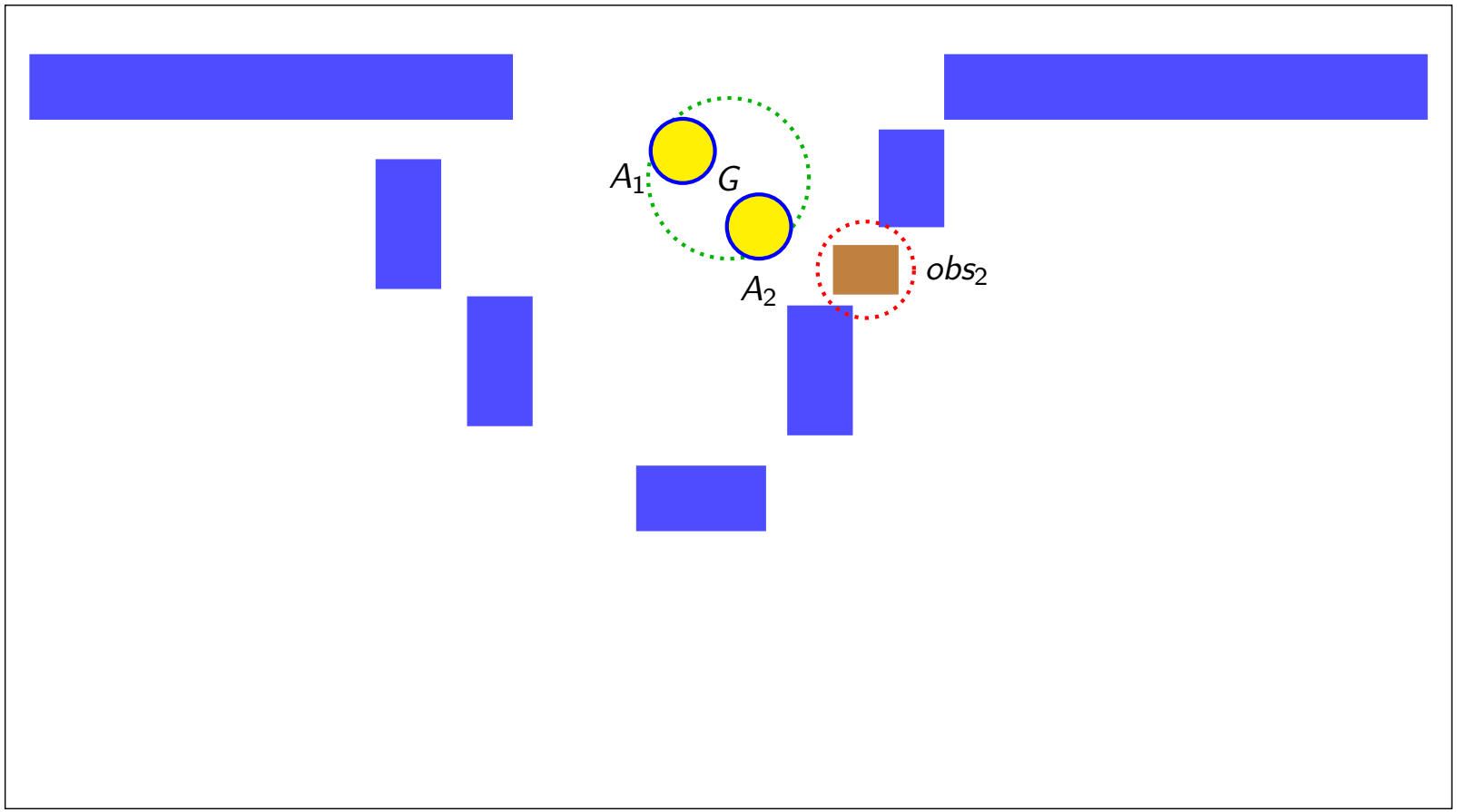

Activated signs for agent $A_2$: "place $Y_1$", "near", "obstacle 1", "destroy".

# Case study




Activated signs for agents $A_1$ and $A_2$: "far", "move 3" $\rightarrow$ path planning operations.

# Case study




Activated signs for agents $A_1$ and $A_2$: goal state ("place G").

# Thank you for attention!

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https://www.hse.ru/en/staff/apanov