Neuroevolutionary phenomenology of communicating agents

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Goal of the project: Evolution of communication

- Communication is evolutionarily complex!
  - late evolution
- Communication is evolutionarily simple!
  - It evolves as soon as needed.
- Answer depends much on the concept of communication.
  - Shannon-like information transfer
  - intentional knowledge transfer (gradual notion)
  - animal communication: different degrees of intentionality and knowledge

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Principles of the project

- Artificial evolution of communicative behavior
- Extremely reduced environment
- Extremely reduced sensomotoric capabilities
- Controllable evolutionary conditions
- Kind of neural substrate is quite arbitrary

Basic questions

- Evolution of communication
- Evolution of specific communicative acts
  - imperatives,
  - questions,
  - assertions
- Evolution of meaning / concepts
- Evolution of pragmasemantics
  - Maxims of conversation, implicatures
  - Robustness of communication

Two kinds of development

- ontogenetic development: learning
- phylogenetic development: evolution
- sharpness of the distinction rests on the precise definition of the individual whose lifecycle is considered
- A capacity can evolve within an agent or a society of agents, it's evolution is not depend on agent evolution.

Biology vs engineering

Neurodynamic evolution can be viewed as providing

- a model for biological evolution,
- an engineering tool for the development of robust economical systems for some predefined tasks.

The evolution can be viewed more or less abstract wrt physical and biological conditions.

The implementation

The environment

- agents moving in a two dimensional environment with different types of entities
  - “food”
  - “walls”

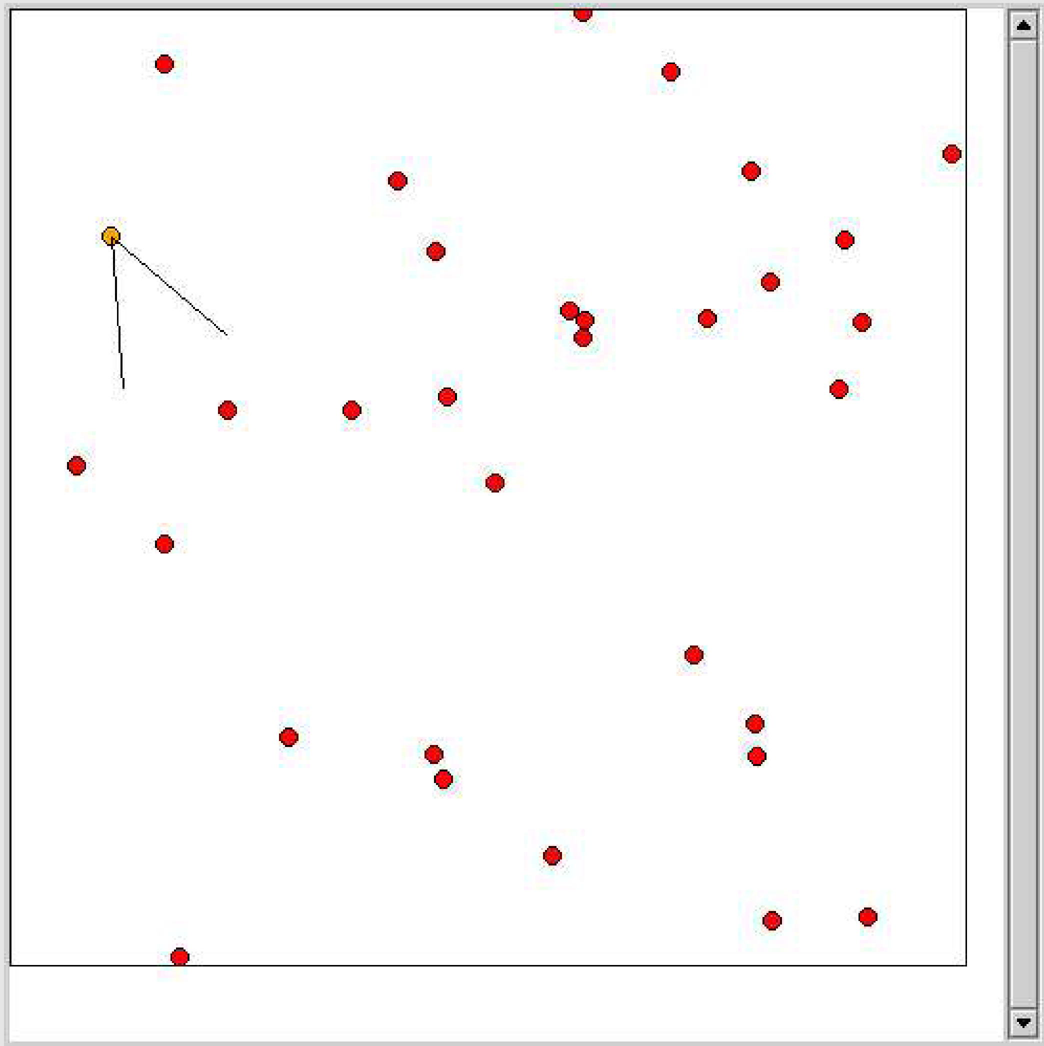

Figure 1: The agents' world

The agents

- food-related goals
- agents perceive the entities of their environment
- agents move within their environment
- sensomotoric relation completely defined by a neural network
- synaptic structure does not change during lifetime of an agent (no built-in learning mechanism)

Constant synaptic structure does not preclude adaption/learning during lifetime!

But you do not get learning for free!

The evolution

- mutation: random change of the neural structure of an agent
- evaluation: measuring the fitness of an agent
- selection: reproduction according to fitness

examples: n3,0; dump1:99th gen

The structure of the agents

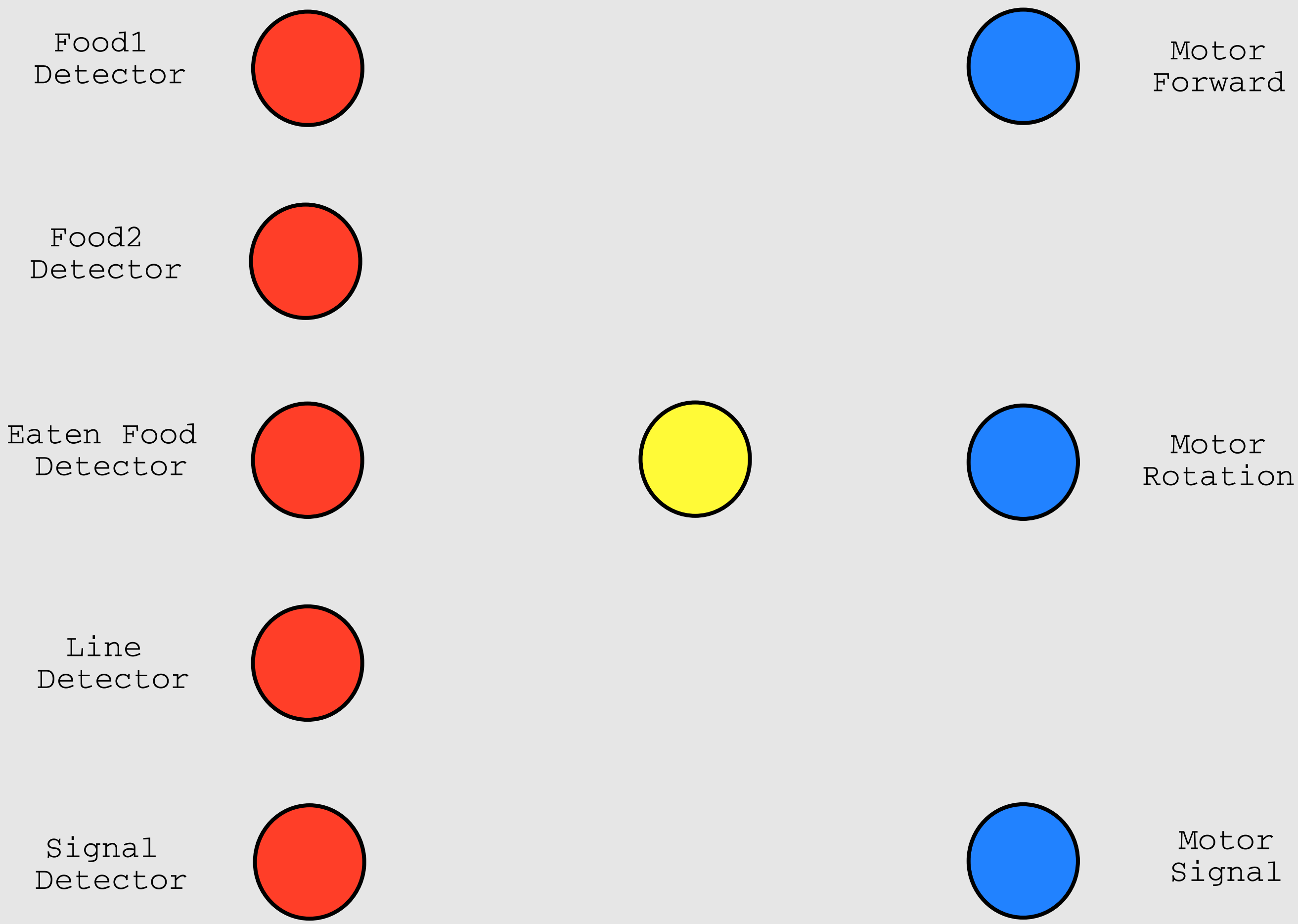

Figure 2: Base neurons.

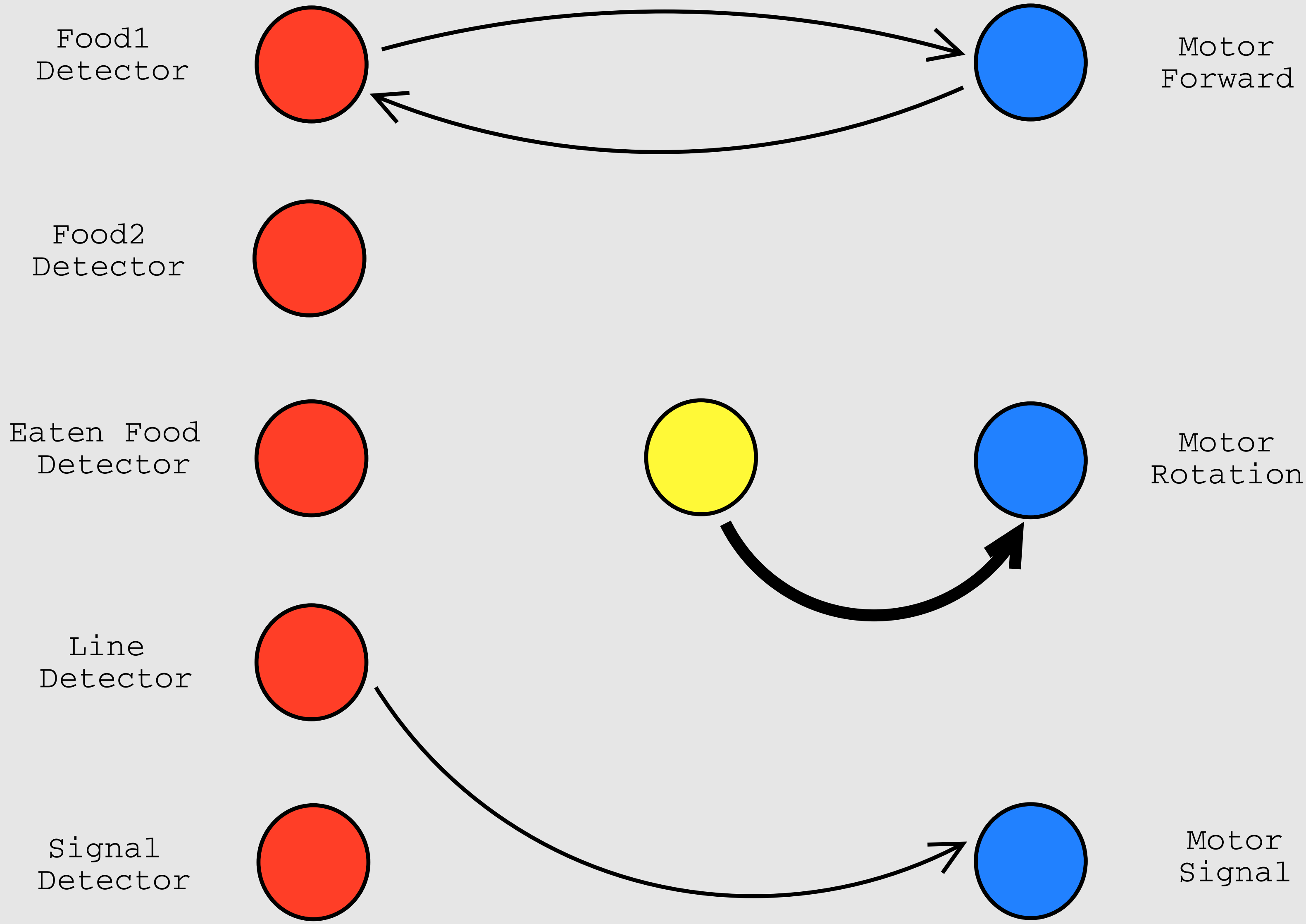

Figure 3: Base neurons with synapses.

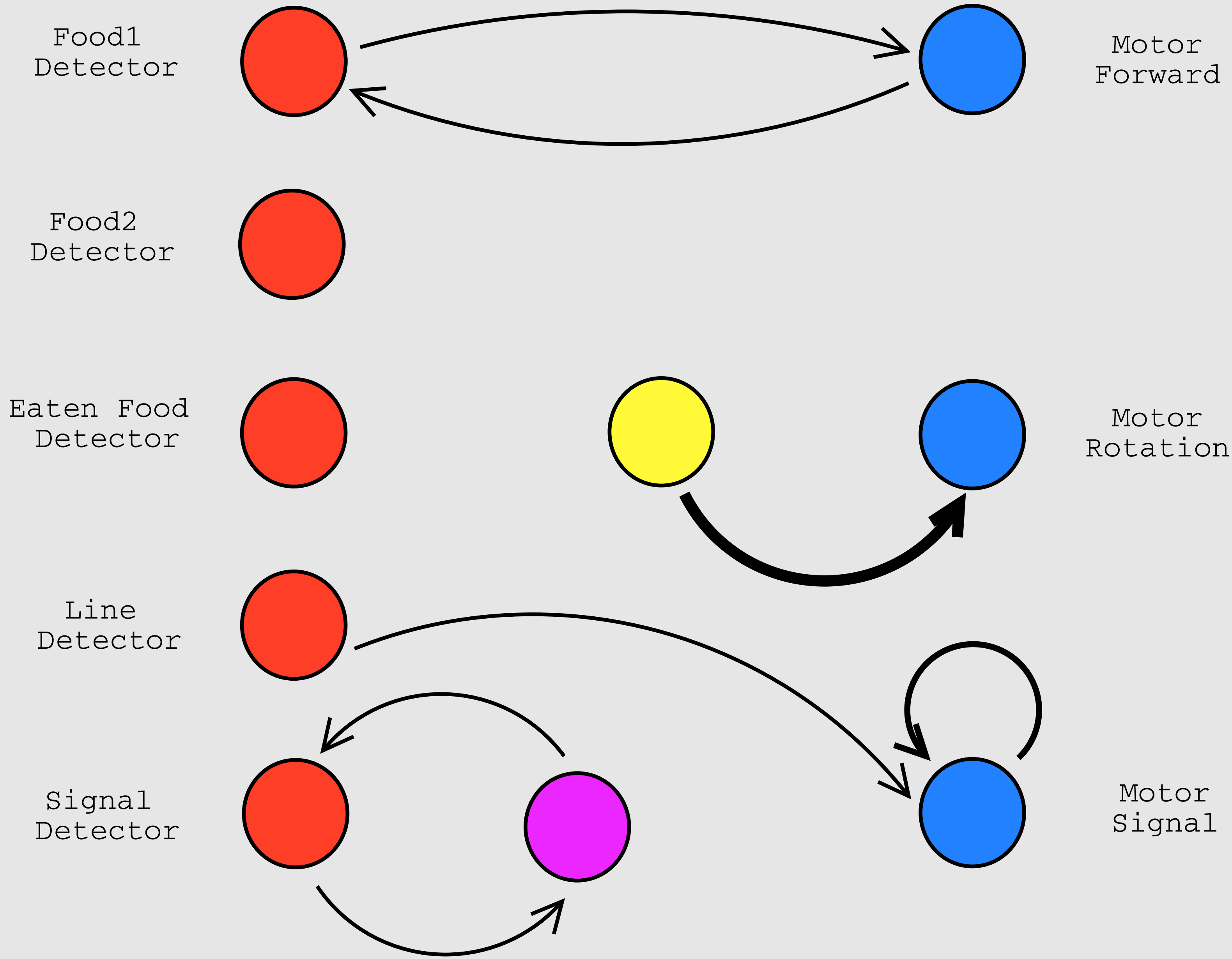

Figure 4: Random mutations

The structure of the neurons

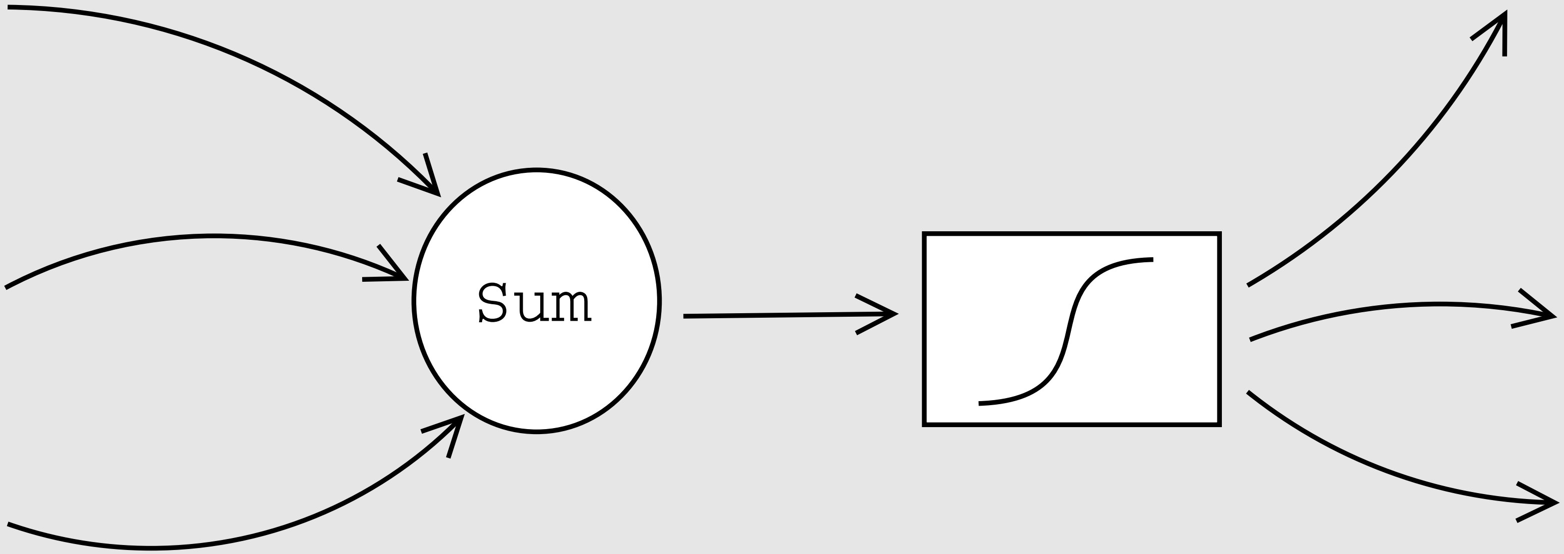

Figure 5: Structure of neurons

Computation of neural states

$$s_{i,t'} = \sigma(p_i + \sum_j w_{i,j} s_{j,t}) \quad (1)$$

$$\sigma : \mathbb{R} \mapsto [1, -1] \quad (2)$$

$$\sigma(x) := \frac{2}{1 - e^{-x}} - 1 \quad (3)$$

$s_{i,t}$: activation of neuron i at time t

$w_{i,j}$: weight of synapsis from neuron i to neuron j, may be negative (inhibitory)

p_i: sensory input to neuron i

Sensory input

$$p_i = \sum_{e \in V} (\left(\frac{\delta_e}{\delta_h}\right)^2 + 1)^{-1} + \nu \tag{4}$$

$$0 < (\left(\frac{\delta_e}{\delta_h}\right)^2 + 1)^{-1} \leq 1 \tag{5}$$

V**:** set of visible entities

δ_e**:** distance of entity e

δ_h**:** distance of half intensity

ν**:** noise

downward monotonous wrt distance δ_e

perception and memory

Multiagent societies

- Agents in each society share internal structure
- Social tasks, coordination needed
- Agents perceive each other

examples: dump6_gen11, dump6_gen20

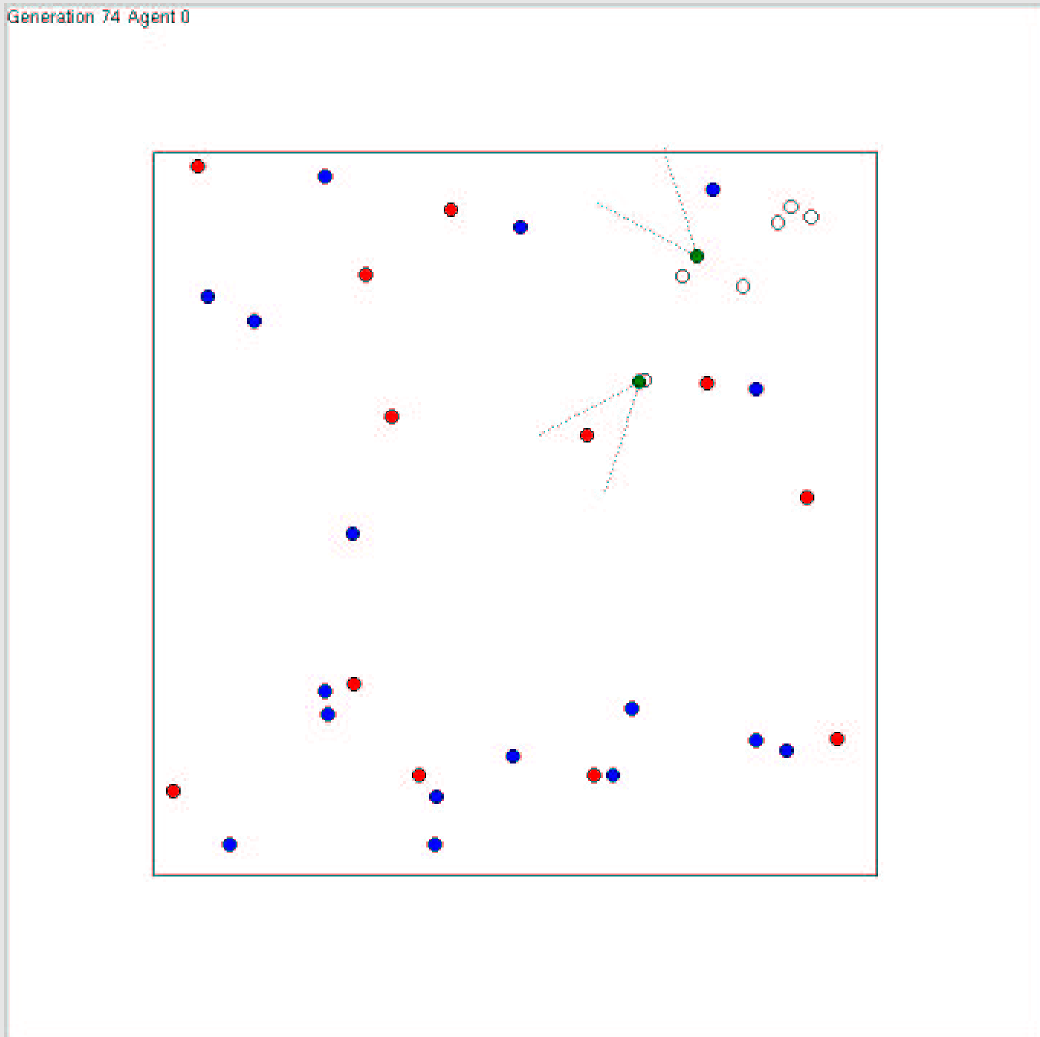

Figure 6: The world of an agent society

Evolution

- Mutation
- Evaluation
- Selection

Fitness

$$F = -N + \sum_{a\in\{1,2\},c\in\{r,b\}} e_{a,c} - \prod_{a\in\{1,2\}} e_{a,r} - e_{a,b} \tag{6}$$

Fitness is high if each agent concentrates

- on a specific kind of food
- different from the other agent.

Mutation

$$A_{n+1} = \{a_m | \exists a[a \in \mathbf{Fittest}_i(A_n) \wedge a_m \in \mathbf{Mut}_j(a)]\} \qquad (7)$$

- n: number of generation
- A_n: set of agents of generation n
- $\mathbf{Fittest}_i(A)$: set of the i fittest agents of A
- $\mathbf{Mut}_j(a)$: set of j mutants of agent a

Evolutionary parameters

- sensomotoric structure of agents
- fitness function
- mutation rate (costs of mutations: new neurons, synaptic changes)
- episode length
- variation of situations
- number of agents per generation
- selection function

Evolutionary milestones

3rd generation: movement

8th generation: forward movement

11th generation: avoid hitting an obstacle

12th generation: seeking of food

30th generation: strongly differing behavior

60th generation: agents informing each other about division of labor

No clear forms should be expected in early development. Evolved strategies are very situation specific.

Evolutionary phenomenology

Signalling

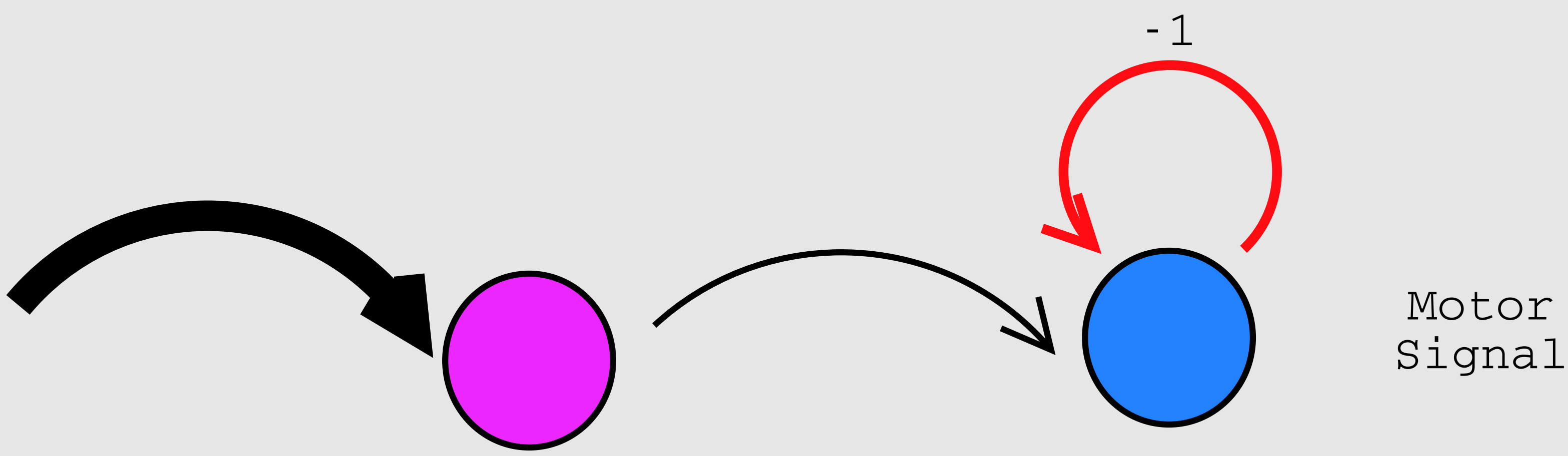

Figure 7: Blinking signal, period=2

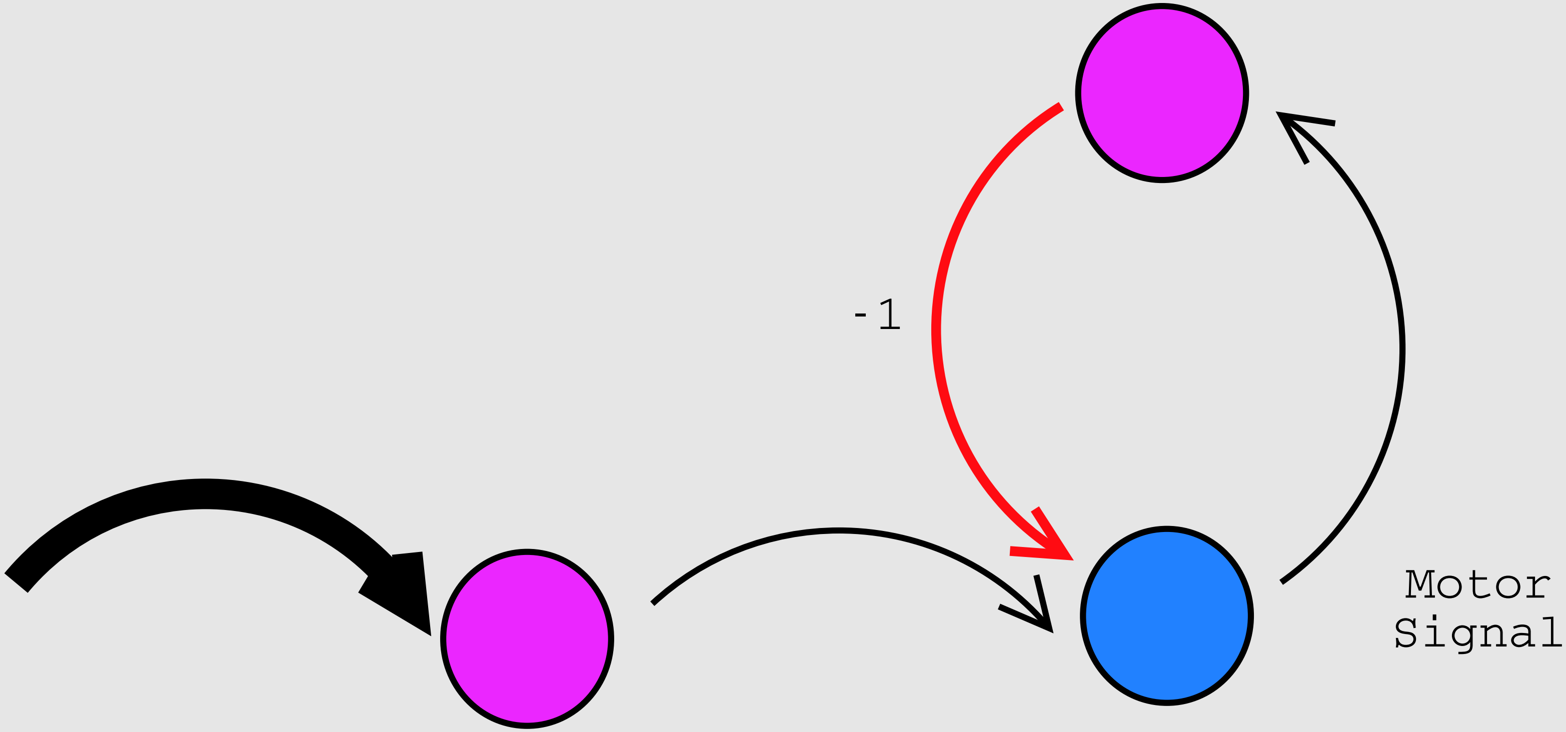

Figure 8: Blinking signal, period=4

Detecting signals

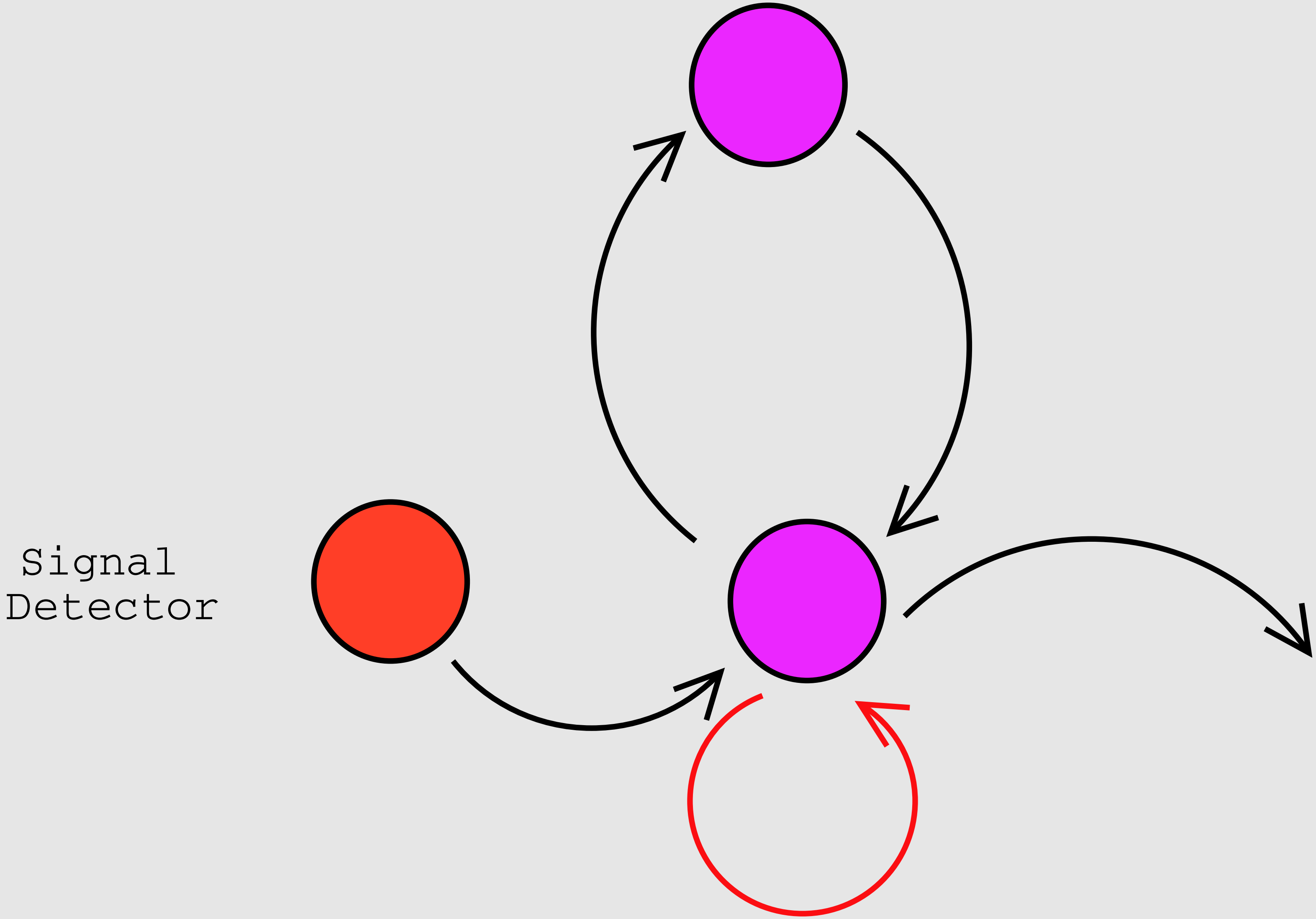

Figure 9: Detecting blinking signal, period=2

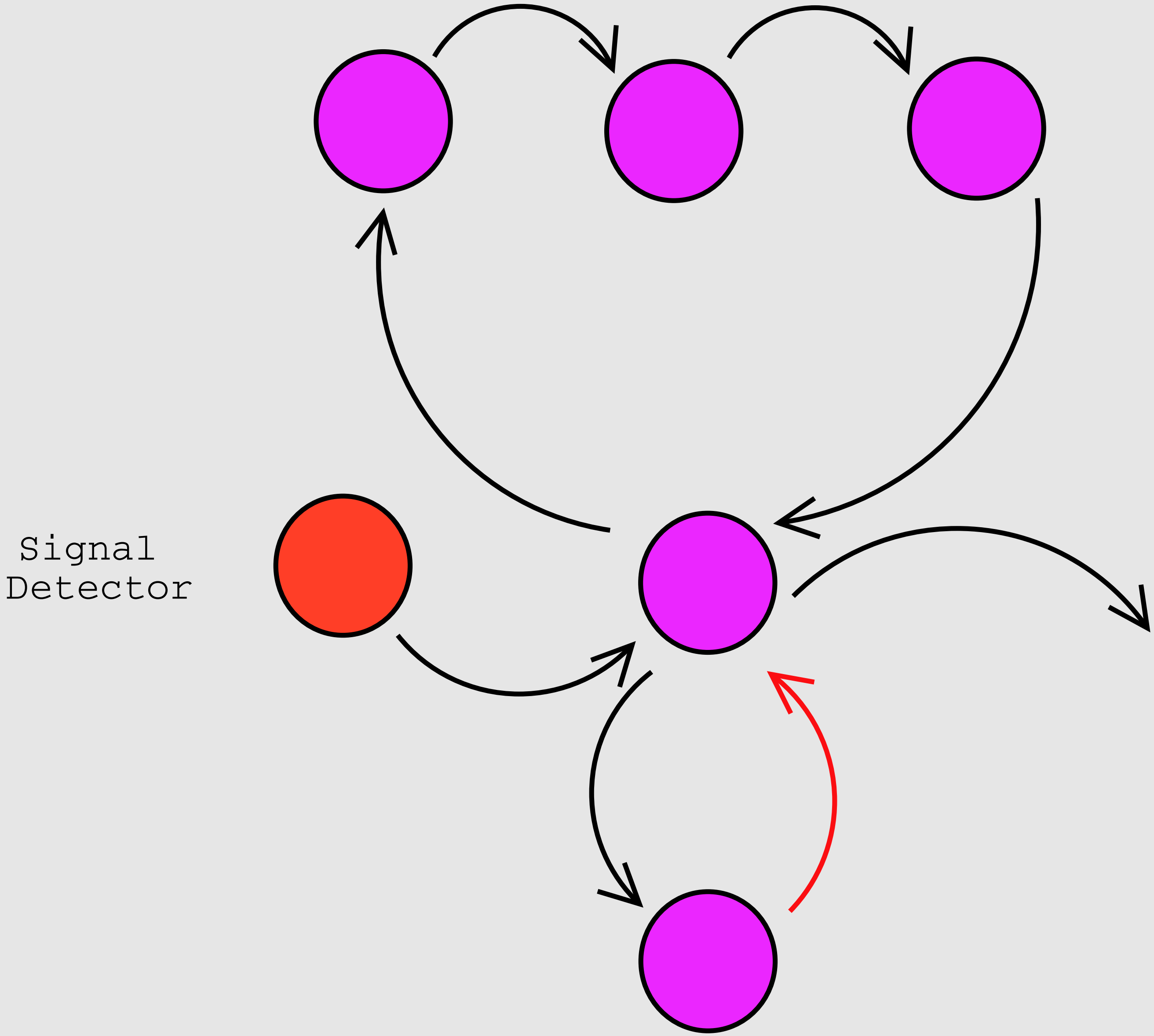

Figure 10: Detecting blinking signal, period=2

Switches

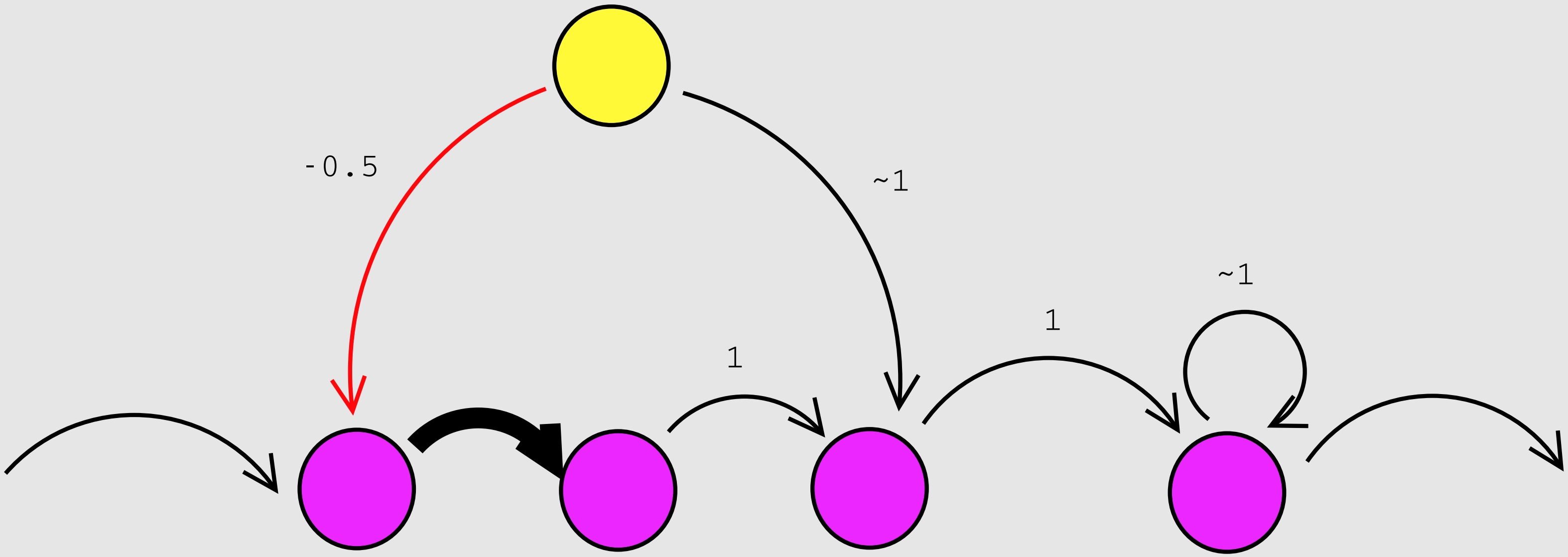

Figure 11: Switch

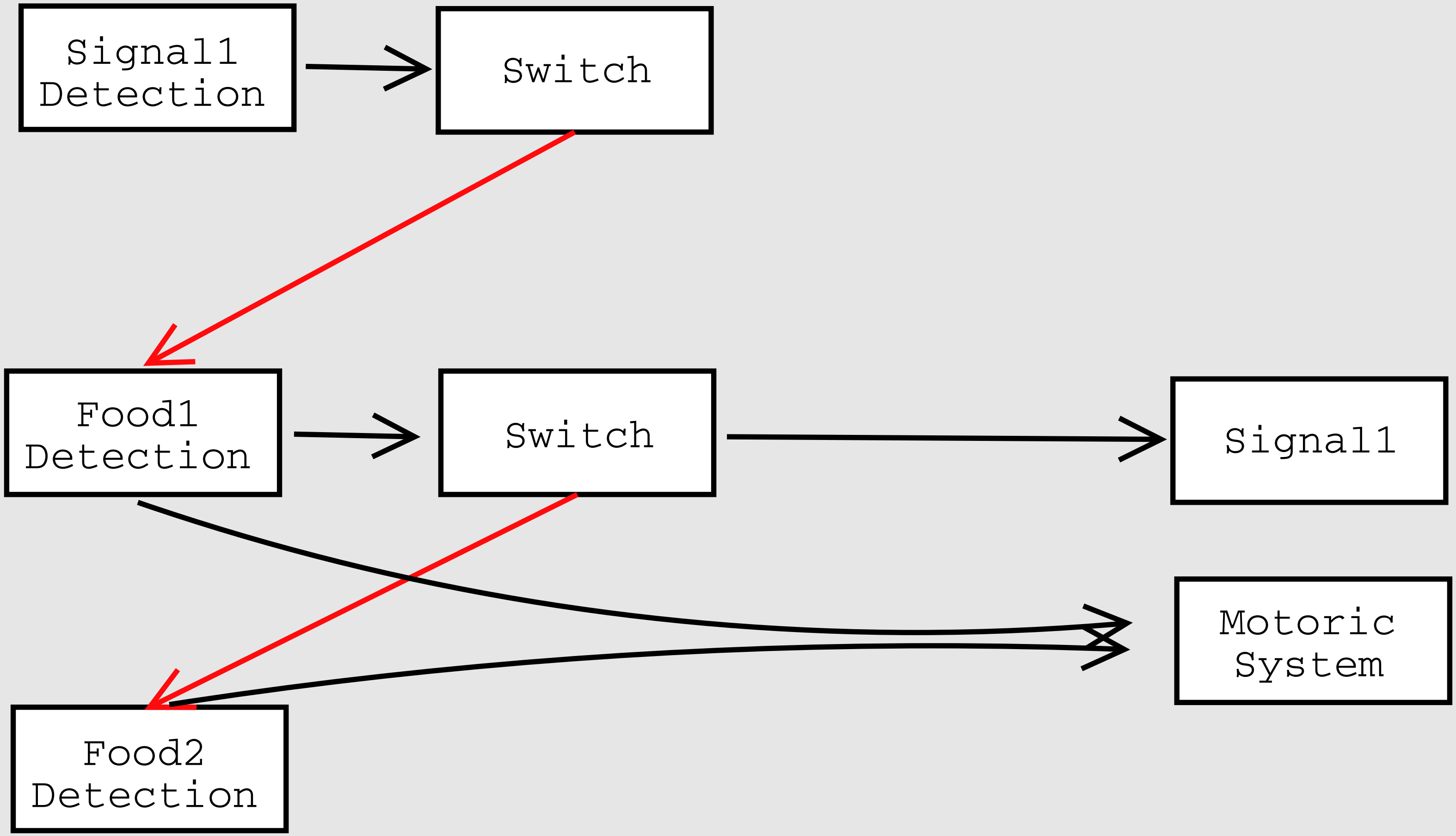

Figure 12: Structure of an agent

Networks in reality

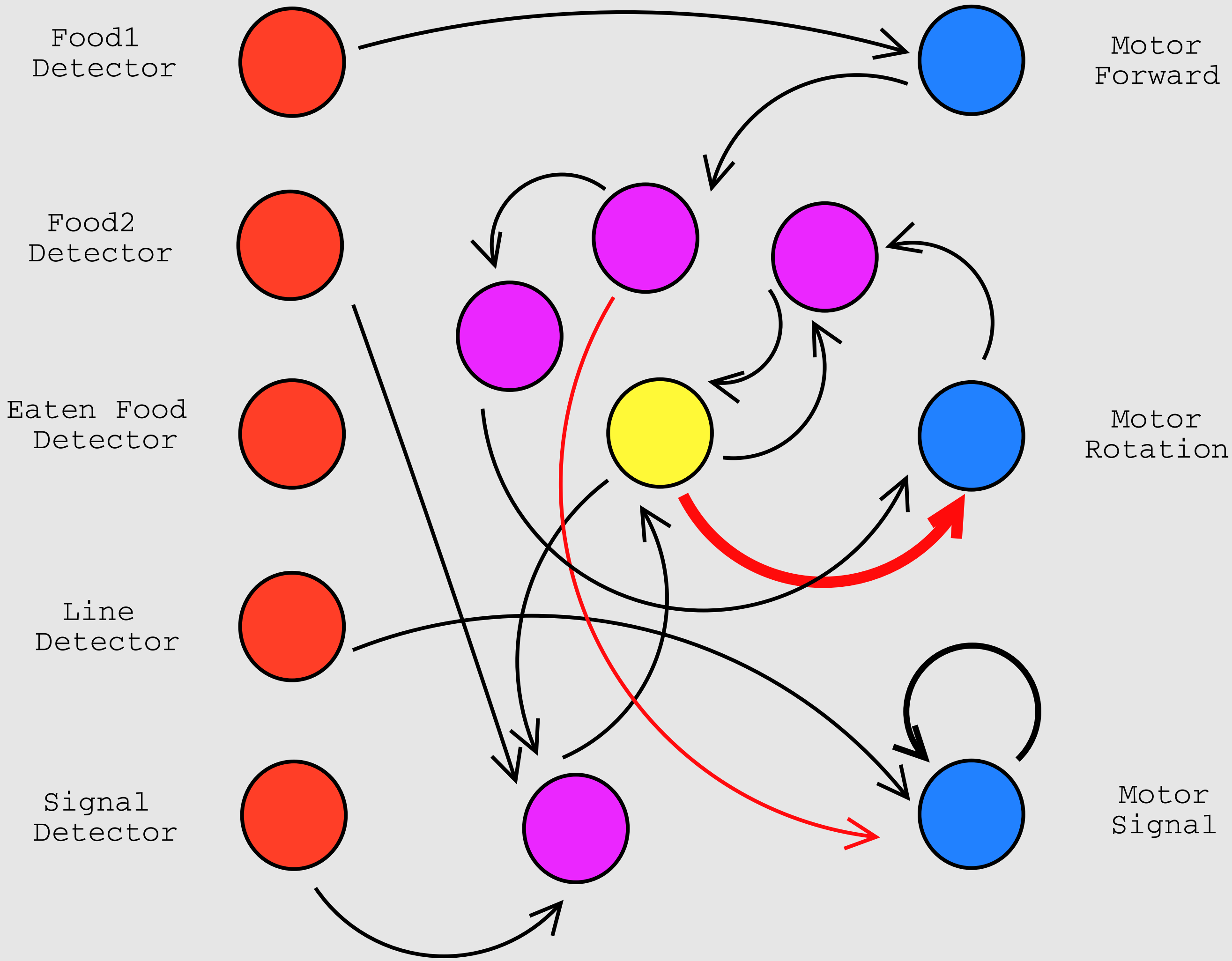

Figure 13: Network in reality

Some extrapolations

Human(-like) communication is characterized by

- syntactic complexity,
- use of / relatedness to concepts and knowledge.

Syntactic complexity

- combinatorial complexity:
  - number of distinguishable item,
  - combining items.

  Related to goals which need highly differentiating communication.
  - neural implementation: intermediate layer with many neurons

Concepts and knowledge

- stimulus-response indirectness:
  - motions are not related to perceptions in a simple and transparent way,
  - stimulus-response relation is adaptive.

  Related too goals which presuppose
  - a history of perceptions (experience),
  - complex computations (reasoning).
  - neural implementation: many intermediate layers

Conclusion

Neurodynamic evolution of communicative behavior

- can evolve in minimalistic environments,
- is not much more complex than the evolution of other sensomotoric capacities,
- needs limited neural ressources.

Definition of tasks and setting of evolutionary parameters is crucial for the speed and the success of the evolution.