Human-like artificial creatures

3. Norns & neural networks

Cyril Brom
Faculty of Mathematics and Physics
Charles University in Prague
brom@ksvi.mff.cuni.cz

Outline

1. Gentle introduction to Norns
   - the architecture
   - the body
   - the breeding algorithm
2. Gentle introduction to neural networks
3. A network of a norn's brain
4. Possibilities and limitations

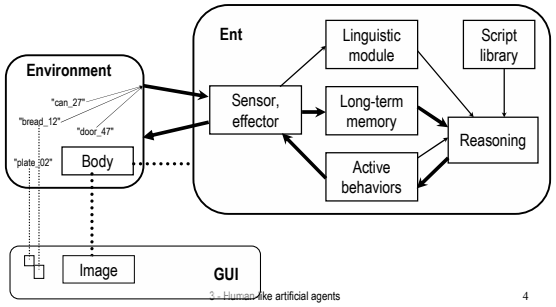
⇨ norns

Ad norns…

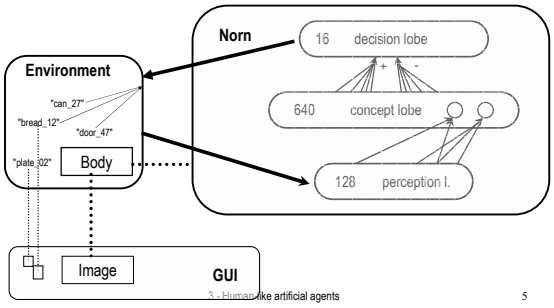
- They live in an artificial environment similar to natural world
- User can observe them and interact with them in a 2,5D GUI
- They are controlled by a neural network comprising about 1000 neurons.
- They speak using "verb-object" sentences
- They are equipped with a body
  - drives: hunger, thirst,...
- They grow and breed through sexual reproduction

1996, Grand, Clif (c)

Overall architecture of a cognitive beast

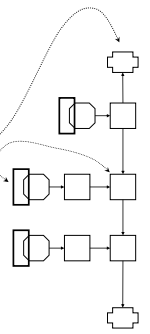


Overall architecture of a norn



The body

- About 20 internal drives
  - fear, boredom, anger, hunger,…
- Biochemistry
  - chemicals (concentrations of H_20, glucose,…)
  - emitters (emit chemicals)
  - receptors (monitors concentrations)
  - reactions: glucose => CO_2 + H_20 + energy
- Chemicals are produced by emitters
  - by acting in the world
  - by internal emitters
- Chemicals reduce or increase drives
- Biochemistry is defined genetically in partial

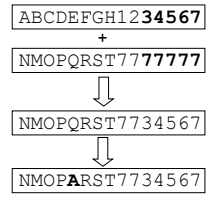


Evolutionary algorithms

- Evolutionary algorithms:
  - an umbrella term used to describe computer-based problem solving systems which use computational models of some of the known mechanisms of evolution
- 1975: Genetic Algorithms:
  - John Holland: "Adaptation in Natural and Artificial Systems"
  - a model of machine learning which derives its behavior from a metaphor of some of the mechanisms of evolution in nature
  - abstraction at the level of individuals
  - a population of individuals represented by chromosomes, in essence a set of character strings... the individuals in the population then go through a process of simulated "evolution"
    - strings = "genome"
    - encoding solutions to the "genomes"
    - fix-length, linear (typically)

[Hitchhiker's guide]

Genetic algorithms



- A population
- Generations
  - parents vs. offspring
- Operators
  - crossover, mutation, selection
  - fitness
    - "take the genomes encoding solutions with the better fitness"

GA

```
PSEUDO CODE
    Algorithm GA is

        // start with an initial time
        t := 0;

        // initialize a usually random population of individuals
        initpopulation P (t);

        // evaluate fitness of all initial individuals of population
        evaluate P (t);

        // test for termination criterion (time, fitness, etc.)
        while not done do
            // increase the time counter
            t := t + 1;

            // select a sub-population for offspring production
            P' := selectparents P (t);

            // recombine the "genes" of selected parents
            recombine P' (t);

            // perturb the mated population stochastically
            mutate P' (t);

            // evaluate its new fitness
            evaluate P' (t);

            // select the survivors from actual fitness
            P := survive P,P' (t);
        od
    end GA.
```

⇨ http://cs.felk.cvut.cz/~xobitko/ga/

Evolutionary programming

- 1966: Evolutionary Programming
  - Fogel, Owens and Walsh: "Artificial Intelligence Through Simulated Evolution"
  - places emphasis on the behavioral linkage between parents and their offspring
  - abstraction of evolution at the level of reproductive populations (i.e. an individual is a species, not an animal)
  - typically does not use any crossover
  - no constraint on representation
    - e.g. a neural network + mutation operates by perturbing a weight vector
- 1992: Genetic programming:
  - John Koza: "Genetic Programming: On the Programming of Computers by Means of Natural Selection"
  - the extension of the genetic model of learning into the space of programs
  - objects that constitute the population are not fixed-length character strings that encode possible solutions to the problem at hand, they are programs that, when executed, "are" the candidate solutions to the problem
  - usually does not use any mutation
  - parse trees, rather than as lines of code (Lisp)
- Immune programming, Evolutionary strategies...

[Hitchhiker's guide]

Genetic algorithms in Creatures

- Haploid chromosome
  - each gene carries the genetic instructions for both sexes
  - time-switching
  - outward characteristics + internal structure
    - "red hair", chemo-receptors, weights in the brain,...
- Cross-over + Mutation

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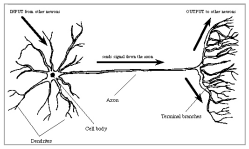
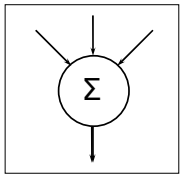
1. Gentle introduction to norns
2. **Neural networks**
   - intro
   - a neuron of a norn's brain
   - a topology of the network
   - a perception layer
   - a concept layer
   - dendrits
   - reinforcement learning
3. Possibilities and limitations

A classical artificial neuron is…

...it is a model of a natural neuron network [McCulloch & Pitts, 1943]

- Oversimplified from the point of view of state-of-art neurobiology
- Every artificial neuron is a function that from an input vector counts an output value
  - weights vs. bias





An artificial neural network is…

...composed of artificial neurons

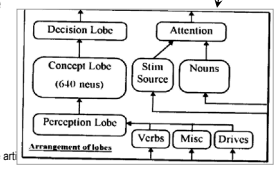
- Topology:
  - layered, recurrent...
  - input neurons / input layer
  - output neurons / layer
  - a multi-layered perceptron, ADALAINE, Hopfield, self-organizing map,...
- Weighted connections

Learning in artificial neural networks

- Supervised
  - with a teacher
  - it gives the correct answer typically
  - e.g. backpropagation
- Reinforcement
  - the environment is the teacher
  - it says whether the action taken has been correct or wrong – reward vs. punishment
  - e.g. q-learning
- Unsupervised
  - without a teacher at all
  - e.g. clustering (based on similarities of input patterns)
- Hebbian principle
  - originally, a hypothesis for how neuronal connections are enforced in mammalian brains [Hebb, 1949]
  - difficult to verify in a mammalian central nervous system

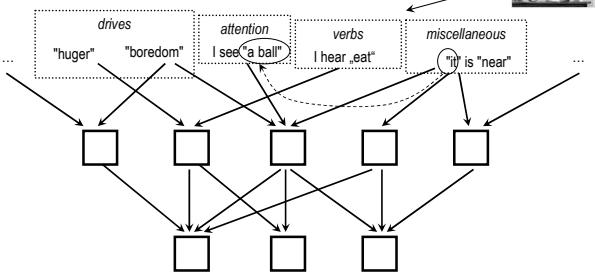
A norn's brain

- Composed of several blocks (lobes / layers) of neurons
- Input lobes process internal and external inputs
- Output lobes determine the next action to execute, i.e. "a top-level" task, a script
- Information spread through the network from input lobes to output lobes
  - "a water pipe"

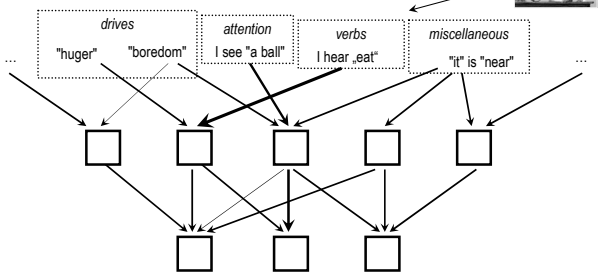


1996, Grand, Clif (c)

A norn's brain



A norn's brain



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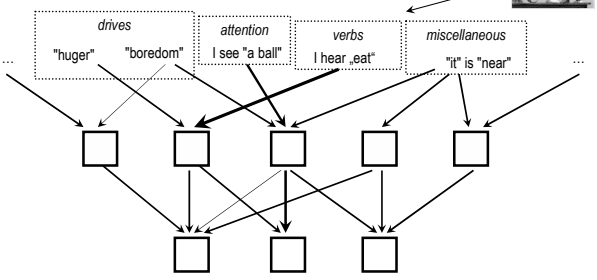
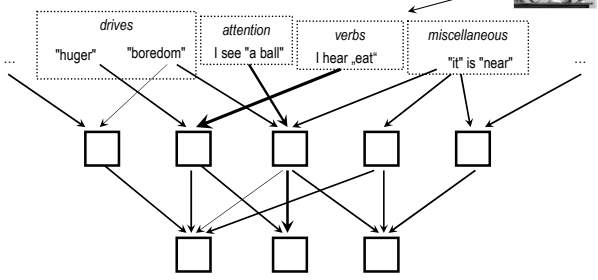
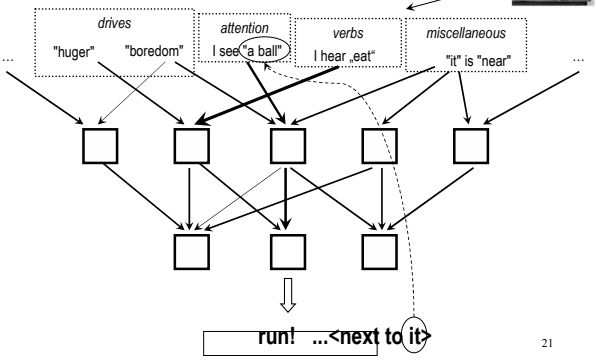


A norn's brain

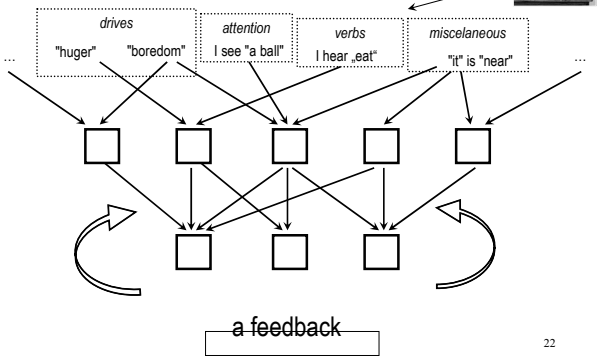


A norn's brain



science kit

A norn's brain



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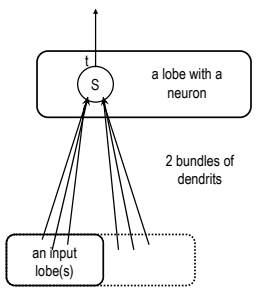
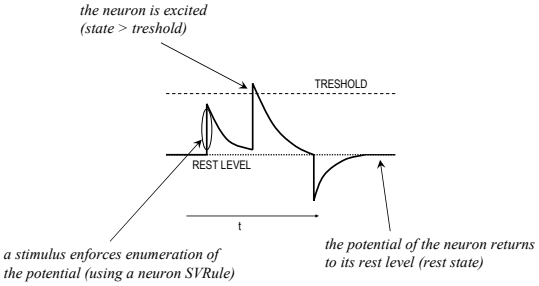
   - reinforcement learning
3. Possibilities and limitations

A neuron of a norn's brain



- s – an **internal potential** of the neuron; it goes towards a rest state (a **relaxation rate**)
- s_r – a **rest state**; defined genetically
- t – a **treshold**; an output of the neuron is counted as follows:
  - output = 0 iff s < t
  - output = s iff s >= t
- a **neuron SVRule** is a function that computes a value of the potential
  - s := state PLUS type0
  - s := state PLUS type0 MINUS 1
  - s := anded0
- **gain** – a relevance of the neuron

A neuron of the norn's brain



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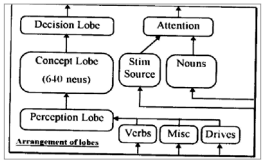
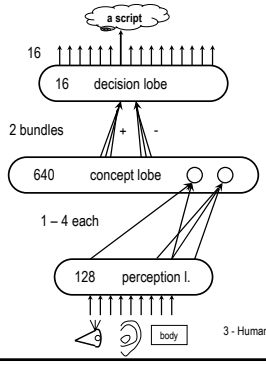
Parts of the brain

- Action selection
- Attention selection



Organization of the brain

Action selection

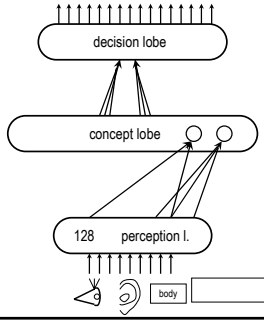


The purpose: to select an action

- **decision lobe** – chooses the best action according to the current situation
- **concept lobe** – remembers interesting/frequent situations (i.e. combinations of perceived symbols)
- **perception lobe** – each neuron represents the presence or absence of a "symbol" in the perceptional system

Organization of the brain

Action selection – an example

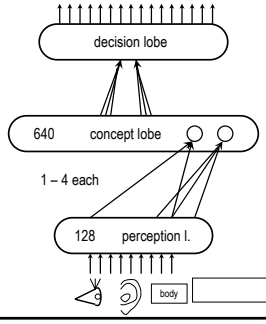


it is perceived –

- sleepiness, tiredness, boredom: high
- seen: a toy + it is "near"
- heard: "play" (verb) + "toy" (object)

Organization of the brain

Action selection – an example



useful concepts – these neurons match:

1. I'm sleepy (sleepiness is high)
2. I'm tired (tiredness is high)
3. I can play (a toy is seen + it is near)
4. I'm advised to play ("toy" heard + "play" heard)
5. I can play and I'm advised to play ("toy" heard + "play" heard + a toy seen + it is neer)

it is perceived –

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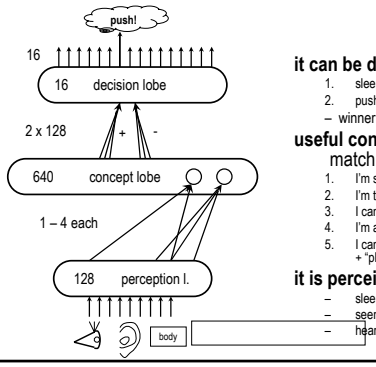
Organization of the brain

Action selection – an example



it can be done –

1. sleep
2. push (a toy)

– winner takes all!

useful concepts – these neurons match:

1. I'm sleepy (sleepines high)
2. I'm tired (tiredness high)
3. I can play (a toy seen + it is neer)
4. I'm advised to play ("toy" heard + "play" heard)
5. I can play and I'm advised to play ("toy" heard + "play" heard + a toy seen + it is neer)

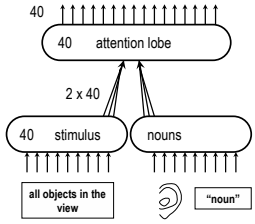
it is perceived –

– sleepiness, tiredness, boredom high
– seen: a toy + it is "near"
– heard: "play" (verb) + "toy" (object)

Organization of the brain

Attention selection

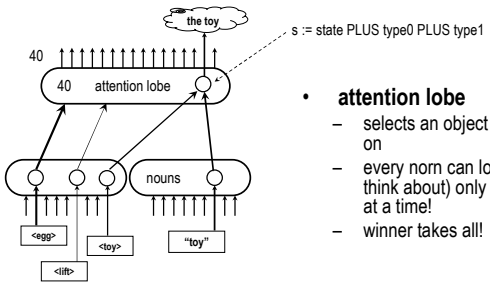
The purpose: to focus on exactly one object



- **stimulus lobe**
  - every object type (in the view) is represented by one neuron
  - individual stimuli are based on the eye appeal of the object, its distance from the norn and the norn's genome (neuron's gain)
- **nouns lobe**
  - a neuron fires when the norn hears a corresponding word:
    e.g.: "play toy"

Organization of the brain

Attention selection



- **attention lobe**
  - selects an object to focus on
  - every norn can look at (and think about) only one object at a time!
  - winner takes all!

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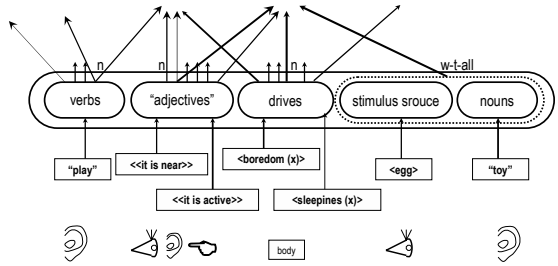
Perception lobe

- It processes visible, audible and internal events
- It contains 4 sub-lobes (technically a copy of their outputs)
- Totally, it contains 128 neurons
  - it means every norn recognizes 128 symbols
- 0-n neurons form each sub-lobe can fire (with one exception)
- All outputs are connected to the concept lobe
  - each neuron in the concept lobe can have 1-4 input dendrits
  - each neuron in the concept can have only one input dendrit from each sub-lobe (with one exception)

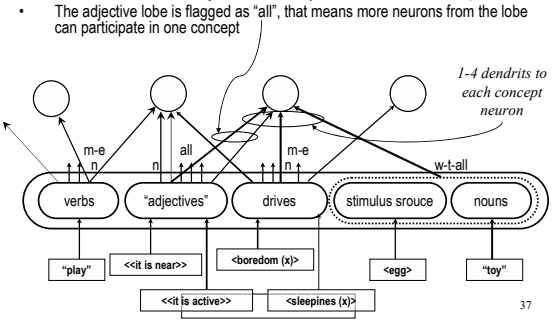
Perception lobe



- "stimulus-source + nouns" is a copy of the attention lobe
- 0-n neuron from each sub-lobe can fire (except of the attention lobe copy)

Perception lobe

- Verbs and drives are "mutual-exclusive" lobes, that means at most one dendrit from the verbs/adjectives lobe may feed an individual concept neuron
- The adjective lobe is flagged as "all", that means more neurons from the lobe can participate in one concept



Perception lobe

verbs – actions	drives	objects	other ("adjectives")
• nothing	• pain	• current norn	• I've been patted
• push	• need for pleasure	• user	• I've been slapped
• pull	• hunger	• call button	• I've bumped into a wall
• stop	• *coldness* (MAX)	• water	• I'm near a waill
• come	• *hotness* (MIN)	• plant	• I'm in the vehicle
• run	• tiredness	• eqq	• User has spoken
• get	• sleepiness	• food	• Creatures has spoken
• drop	• lonesliness	• drink	• Audible event
• think	• overcrowdedness	• vendor	• Visible event
• sleep	• fear	• music	• It is approaching
• walk left	• boredom	• animal	• It is retreating
• walk right	• anger	• toy	• It is near me
• eat	• sexdrive	• shower	• It is an object
• hit	• injury	• weed	• It is my child
	• suffocation	• mover	• It is opposite sex
	• thirst	• lift	• It has hit me
	• stress	• norn	• …
		• …	

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Concept neuron

an example

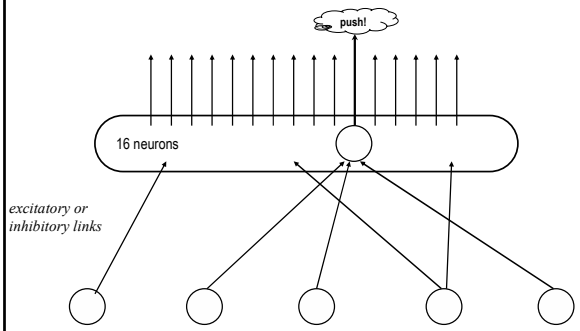
- A concept could be:
  - "play" + "toy" + <toy> + <boredom (high)>
  - <toy> + <<it-is-near-me>> + <<it-is-active>>
  - <norn> + <sex-drive (high)>
  - <norn> + <<it-is-opposite-sex>> + <sex-drive (high)>
- A concept could be (but is not useful):
  - <hotness (high)> + <toy> + "look" + "egg"
  - this concept will be forgotten
- A concept can not be:
  - <toy> + <egg>
  - "play" + "toy" + "push"

Can both neurons "play" and "push" fire simultaneously? Why?

Concept lobe

- Contains 640 concept neurons
- Every concept neuron influences the action selection in a positive or a negative manner
- The initial wiring between the perception lobe and the concept lobe is set genetically with some random noise

Decision lobe



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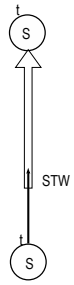
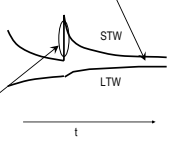
Dendrits

- Everything important happens between neurons
- Main parameters of a dendrit are:
  - **STW** (short-term-weight) – it is not static!
  - **LTW** (long-term-weight)
  - STW/LTW **relaxation rate**
- The output of a neuron is modulated by STW
  - dendrite value = output-of-source-cell * (STW / 255)



Dendrits – STW / LTW

STW goes towards LTW exponentially (relaxation rate) with the LTW being slower



LTW computes moving average of many STW disturbances

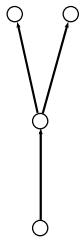
STW is modulated by reinforcement SVRule during a reinforcement episode

Reinforcement learning

- Hebbian learning – "it could be an interesting concept when both neurons fire – strengthen the weight"
  - a **susceptibility** to reinforcement is increased in such situation (by a **susceptibility SVRule**)
  - the susceptibility goes exponentially to 0 (half-time is defined by a susceptibility SVRule)
- Later, **reward** or **punishment** can be generated and STW is changed according to it:
  - STW = STW + (susceptibility / 255) * reinforcement-SVRule
  - reward and punishment are chemicals
    - "hidden" in the reinforcement SVRule

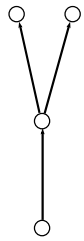
Reinforcement learning

1. Neurons fire, a norn chooses an action



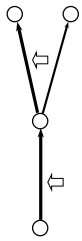
Reinforcement learning

1. Neurons fire, a norn chooses an action
2. All dendrits between all firing p-neurons and firing c-neurons and all firing c-neurons and firing d-neurons are made sensitive



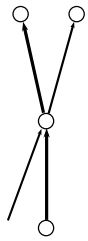
Reinforcement learning

1. Neurons fire, a norn chooses an action
2. All dendrits between all firing p-neurons and firing c-neurons and all firing c-neurons and firing d-neurons are made sensitive
3. Reward or punishment is generated
4. When it "arrives" at a sensitive dendrit, the STW of the dendrit is changed



Reinforcement learning

1. Neurons fire, a norn chooses an action
2. All dendrits between all firing p-neurons and firing c-neurons and all firing c-neurons and firing d-neurons are made sensitive
3. Reward or punishment is generated
4. When it "arrives" at a sensitive dendrit, the STW of the dendrit is changed
5. Susceptibility is being decreased continually, while other neurons are firing



Reward and punishment

How are they generated?

- A set of chemicals is generated inside the body-system when the norn has performed an action (ate food, pushed a toy,…).
- These chemicals increase or decrease a drive and produce the reward chemical or the punishment chemical in the following way:
  - driveraiser => drive + punishment
  - drivereducer + drive => reward
- The meaning of these transformations is:
  - to increase a drive is always bad (e.g. to increase hunger)
  - to decrease a drive is good *iff* the drive is present (e.g. a decrease of "hunger" is good if the norn is hungry)
- Excitatory dendrits are reinforced by reward while inhibitory dendrits are reinforced by punishment

Reinforcement

The meaning

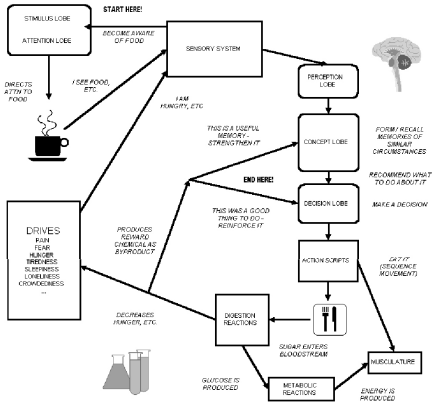
- The meaning of an increase (a decrease) of STW of a dendrit between a c-neuron and a d-neuron is:
  - the action you have performed is appropriate (inappropriate) in the given situation
  - it has been appropriate (inappropriate) that you have NOT performed the action in the given situation

Can you explain it?

- The meaning of an increase of susceptibility of all incoming dendrits of a c-neuron is:
  - this is a good concept to remember
  - otherwise, the connection atrophy and the concept can be eventually forgotten

Dendrits migration

- There are about 128^4 possible concepts – much more than c-neurons!
- Each dendrit has its **strength** (it is not the STW!)
- The strength is strengthen by a constant iff:
  - strength-gain-SVRule > 0
  - e.g.: Increase the value of strength by 3, if "susceptibility>0 and chem3>0"
- The strength is weaken by a constant iff:
  - strength-loss-SVRule > 0
- If the strength of a dendrit is decreased to 0 (or all dendrits comprising a concepts are 0, respectively) the dendrit may migrate to another input neuron



Outline

1. Gentle introduction to norns
2. Neural networks
3. **Possibilities and limitations**

Possibilities

Action sequences

- Action sequencing could appear theoretically:
  1. <hunger (high)> + <food> => walk left
  2. <hunger (high)> + <food> + <<it is near>> => eat it
- The second concept becomes valid after walk left is executed

Possibilities

Robustness

- Consider the following rule:
  - <hunger (high)> + <food> + <<it is near>> => eat it
- The rule is strengthen every time the norn eats
- When some food is rotten, a punishment is generated and the rule is weaken
- Despite the episode with the rotten food, after a while, the rule will fire again, because the STW exponentially increases to the LTW (while the LTW decreases only a little bit)

Possibilities

Generalization

- What is generalization?
  - *I find myself in the situation looking at a big green thing with staring eyes, which I've **never** seen before. Nevertheless, I remember from previous experiments that going up to things with staring eyes and kissing them is not good idea. So, I'll try something else this time.*
  - The creature can deal with situations, in which it has never been before!

Possibilities

Generalization

- What is generalization?
  - *I find myself in the situation looking at a big green thing with staring eyes, which I've **never** seen before. Nevertheless, I remember from previous experiments that going up to things with staring eyes and kissing them is not good idea. So, I'll try something else this time.*
  - The creature can deal with situations, in which it has never been before!
- But what about exceptions...?
  - *This horrible green creatures is my kind aunt, who gives me a lollipop from time to time.*

Possibilities

Generalization

- In this model, generalization is theoretically possible:
  a) <norn> + <<it-is-opposite-sex>> + <sex-drive (high)> => run
  b) <norn> + <<it-is-opposite-sex>> + <<it-is-my-parent>> + <sex-drive (high)> => stop
- The rule (a) holds in both situations

1. Consider a situation that the rule (a) applies for (B)
2. When this happens, a punishment is generated and STW of the $dendrit_{A=>run}$ is weaken and the $dendrit_{B!=>run}$ is strengthen
3. After some repetitions, is becomes:
   $LTW_{A=>run} + LTW_{B!=>run} < LTW_{B=>stop}$. Now, the rule (b) is firing in the situation (B) and STW of $dendrit_{B=>stop}$ is strengthen as a consequence.
4. Later, if the situation (B) occurs again, the rule (b) will apply.
5. The rule (a) will still apply in the situation (A), because (b) does not fire in (A) at all.

- **Summary:** The dendrit from the more general concept to its desired action will have smaller LTW than the dendrit from the more specific concept to its desired action, and/or (perhaps) the more specific concept will inhibit the action of the more general concept. It means that the creatures will have learnt to discriminate between the two concepts.

Limitations

- The attention is focused only to 1 object
  - "subject-verb-object" is not possible
  - e.g. "put egg to hatchery"
- The norn can not deliberately switch attention
  - If a norn is more stimulated by a toy (which is attractive and could be moving) rather then by food (which is not moving), it will be fixated on the toy although it is dying of starvation
    - Can a connection between drive lobe and attention lobe help?
    - Must this wiring be hard-coded or can be learnt by reinforcement?
- The norn has no world-model memory
  - It has a procedural memory, bot does not have episodic memory
  - It is not able to learn where the garden with some food is

Main limitations (reactive planning vs. Creatures' net)

	R.P.:	Creatures:
• Transition	SHRP + FSM	N. A.
• It behaves in the same way	probabilistic	OK?
• Rigid	-	N. A.
• Compromise action	-	YES
• Proscription	-	YES
• Modification of a behavior	BOD	-
• Concurrent behaviour	-	-
• Interleaving	-	-
• Sharp timeout	-	N. A.
• Adaptive	-	partially?
• Time-consuming design	-	KO!

End.

References

Creatures:

- Grand, S., Cliff, D., Malhotra, A.: Creatures: Artificial life autonomous software-agents for home entertainment. In: Johnson, W. L. (eds.): *Proceedings of the First International Conference on Autonomous Agents*. ACM press (1997) 22-29
- The Creatatures Developers Resource: http://www.double.co.nz/creatures/index.htm
  …relevant information, but not updated!

Evolutionary computation:

1. J. Heitkoetter and D. Beasley: THE HITCH-HIKER'S GUIDE TO EVOLUTIONARY COMPUTATION: http://www.faqs.org/faqs/ai-faq/genetic/
2. Interactive Introduction to Genetic Algorithms: http://cs.felk.cvut.cz/~xobitko/ga/
3. John Koza's homepage: http://www.genetic-programming.com/johnkoza.html

Perception lobe