Fuzzy control in Framsticks

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www.framsticks.com

Details of this research
are available in [HKW03; HK08].

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"Walker agent"
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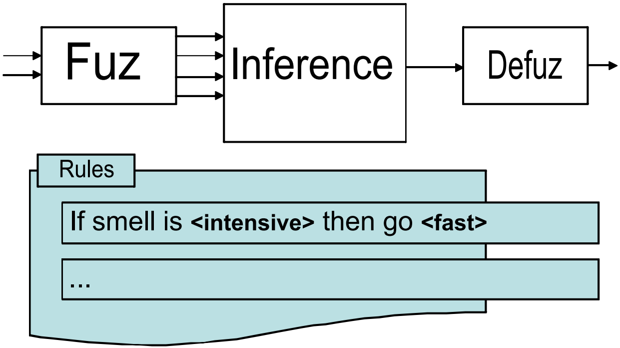
Observations and motivations

- Observations:
  - framsticks move in a way similar to those evolved in nature – e.g. "virtual lizard", "water snake"
  - the simulation confirms that evolution optimizes bodies of different structures to move efficiently
- Questions about the reasons:
  - why creatures behave in such a way?
  - what caused such development of "body and brain"?
- This knowledge is hidden in the brain
- An attempt to explain evolution

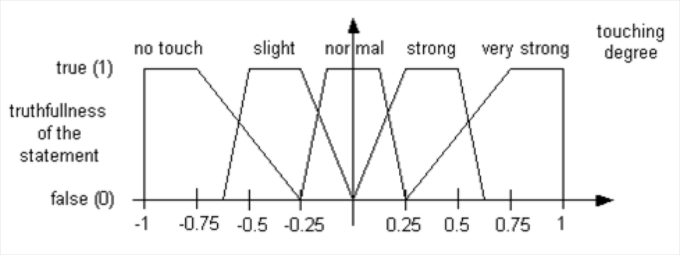
Knowledge representation

- ANN?
- Fuzzy system



Fuzzy variables

- Example – touch sensor
- Normalized variable domain



Fuzzy "neuron"

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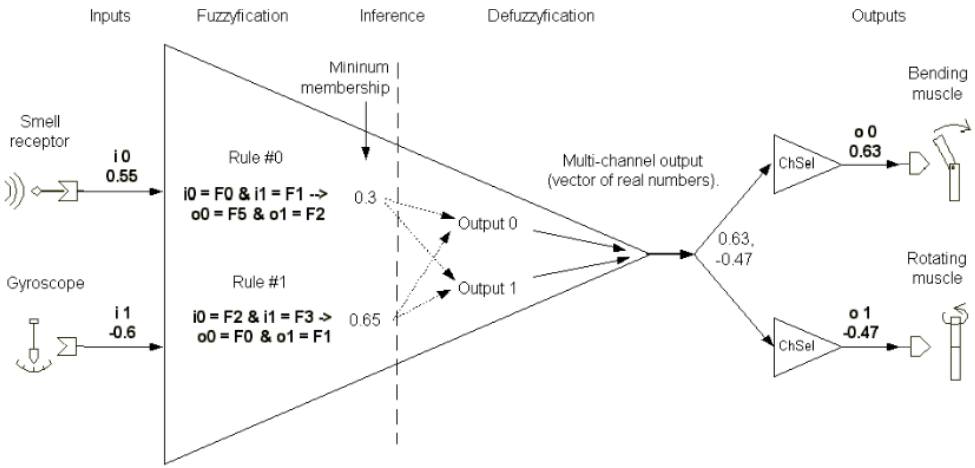
- Fuzzy system representation
- Mamdani approach



Evolutionary encoding of FS

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Fuzzy "neuron" genotype sections:

Def	Fuzzy sets	Fuzzy rules

n:d=**"**Fuzzy: **ns**=4, **nr**=2,
fs=−0.1647; −0.1526; −0.0087; 0.0631;
−1.0000; −0.8774; −0.7725; −0.6767;
0.0087;0.2308;0.3585;0.4806;
0.0110;0.1664;0.2362;0.2718;
fr=0;3;1;0;2;0:0;2;3;1;2;1;1;3
2;0;0;2;1;2:3;1;2;0;1;2;0;0**"**

Example

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The example of a fuzzy rule-based system with two inputs (x0, x1), two outputs (y0, y1), two rules (R0, R1), and five fuzzy sets (F0 .. F4):

F0=$\{-0.35;\ 0.05;\ 0.4;\ 0.65\}$
F1=$\{-1;\ -0.8;\ -0.8;\ -0.35\}$
F2=$\{0.2;\ 0.5;\ 0.7;\ 0.8\}$
F3=$\{-0.65;\ -0.5;\ -0.3; 0.1\}$
F4=$\{0.4;\ 1;\ 1;\ 1\}$
R0: IF x0 is F0 AND x1 is F1 THEN y0 is F5 AND y1 is F2
R1: IF x0 is F2 AND x1 is F3 THEN y0 is F0 AND y1 is F1

Evolutionary operators – mutation

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- Add/femove a fuzzy set
- Add/remove a fuzzy rule
- Add/remove an input/output

Evolutionary operators – crossover

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- One/multiple crossing points
- Two parents, one descendant
- Parents may be of different length
- Crossover and inheritance
  - Draws the number of rules
  - For each rule:
    - Randomly chooses a pair of rules from parent1 and parent2
    - Draws the number of inputs and outputs
    - Copies inputs and outputs

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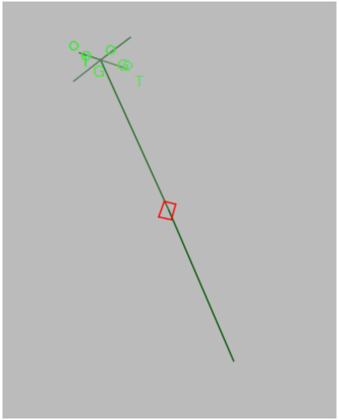
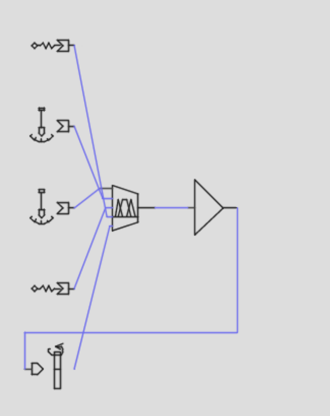
Experiment design

- Goal: to evolve only the "fuzzy brain"
- Fixed body structure (parts, joints)
- Fixed number of receptors
- Variable number of fuzzy sets
- Variable number of fuzzy rules

Experiment: "Stand-up agent"

- Inputs: 2 gyroscopes, 2 touch sensors
- Output: muscle





Experiment: “Stand-up agent”

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- Fitness function: maximize the average height
- The goal of a FS: to force the agent to stand up
- Two example creatures chosen from the population

Experiment: "Walker agent"

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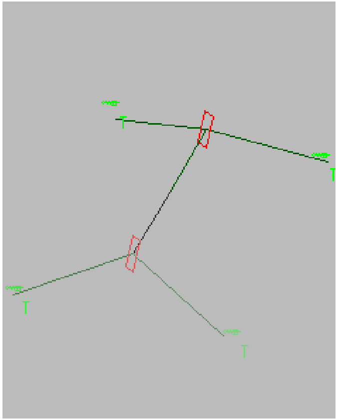
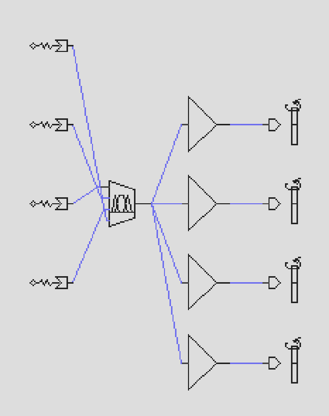
- 4 inputs: touch receptors
- 4 outputs: rotating muscles
- Fitness function: velocity





Video demonstration

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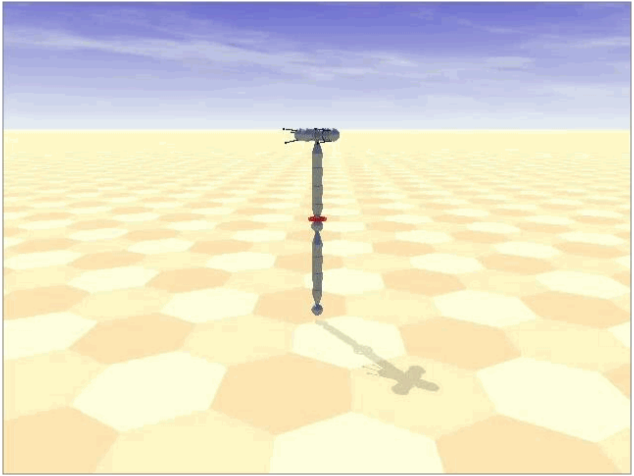


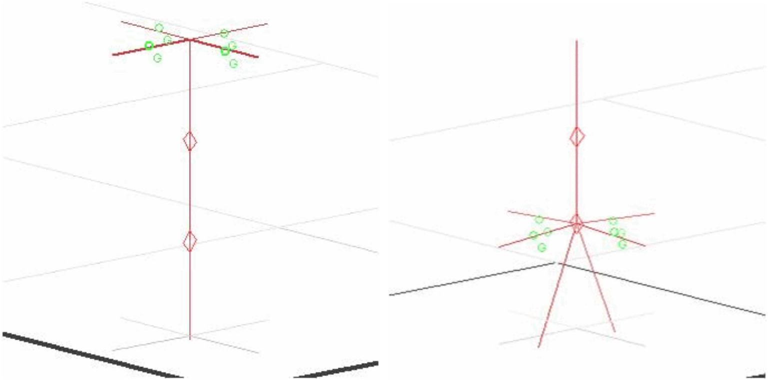
The original video is no longer available, but here is a related one:
https://www.framsticks.com/files/videos/FuzzyControl_hq.mp4

Conclusions – “Walker agent”

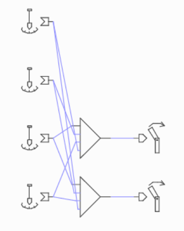
- Behavior
  - Slightly jumps using back legs
  - Runs all around, fitness function does not imply straight running
- Two fuzzy rules are sufficient

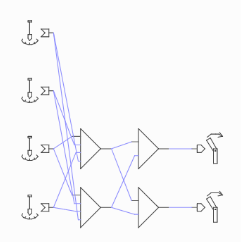
Inverted pendula problem

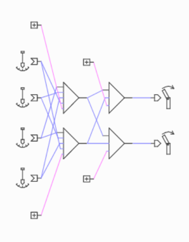
- Modified formulation: active and elastic

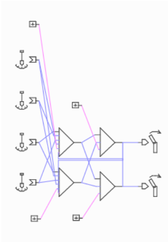


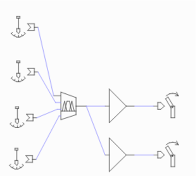
Comparison with NN control











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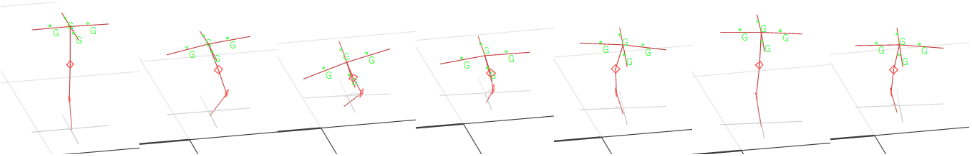
Evolved balancing behavior (NN)



Problems: elasticity and perceptual aliasing

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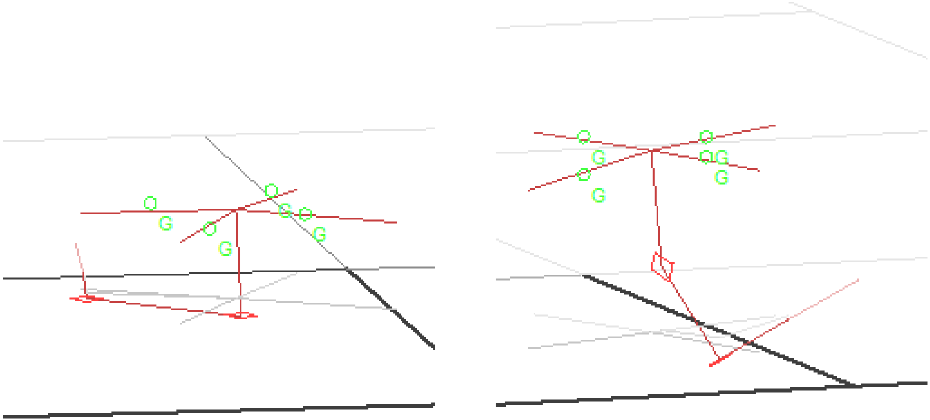

Understanding evolved fuzzy rules – pendulum configuration

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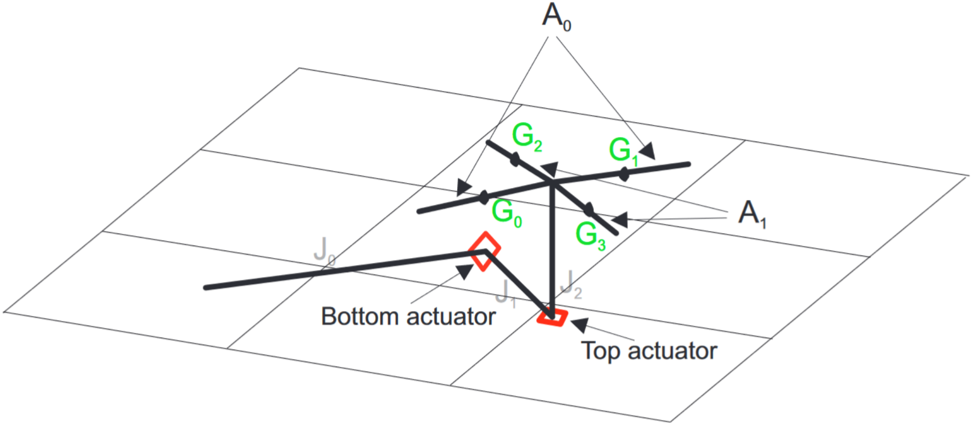

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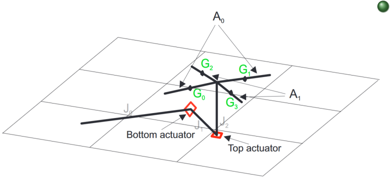

- in the stable position, J_0 and J_1 lie down on the ground, while J_2 stands upright supporting the head in the horizontal position
- after the pendulum is manually thrown off balance, it reaches the stability quite quickly and the behavior strategies depend on the side it has been pushed to:
  - if it has been pushed along its bottom joint (J_0), the actuators are bent only slightly,
  - if it has been pushed crosswise to the J_0, it makes sudden moves and after a few cycles it usually reaches the stable position,
  - if the pendulum falls upside down, the fuzzy system is unable to make it stand straight.

Understanding evolved fuzzy rules

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Each fuzzy system has four inputs and two outputs.
Input signals `s0`, `s1`, `s2`, `s3` come from four sensors.
Based on their values, the fuzzy system sends two outputs signals for actuators: `bend_bottom` and `bend_top`.

Input and output fuzzy variables are defined in the normalized domain $[-1, 1]$.
Input linguistic variables `upright, leveled` and `upside_down` are defined as follows: $(-1, -1, -1, 0)$, $(-1, 0, 0, 1)$, and $(0, 1, 1, 1)$.

The outputs characterizing bending directions are expressed by linguistic variables: `right` $(-1, -1, -1, 0)$, `none` $(-1, 0, 0, 1)$, and `left` $(0, 1, 1, 1)$.

Understanding evolved fuzzy rules

```
1. s2=leveled and s0=leveled         => bend_bottom=left and bend_top=left
2. s3=leveled and s1=upside_down     => bend_top=left
3. s1=upright                        => bend_bottom=left and bend_top=left
4. s3=upside_down                    => bend_bottom=right and bend_top=left
5. s1=upside_down                    => bend_bottom=left and bend_top=none
```

- the pairs of sensor signals (s0, s1) and (s2, s3) never come together in a single premise of the rule. That is because the optimization process discovered a property of the pendulum structure: the signals from these equilibrium sensor pairs are almost the same. This is the consequence of placing sensors (G_0, G_1) and (G_2, G_3) on the same arms, respectively.
- see the text for detailed explanation and analysis of each rule.

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- Successful (evolutionary) simplification of the fuzzy system (from 20 to 5 rules)
- both evolution of neural and fuzzy controllers for active inverted pendulum lead to similar pendulum behaviors
- NNs easier to optimize
- verified ability to extract knowledge from the fuzzy control system

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[HK08] Maciej Hapke and Maciej Komosinski. "Evolutionary Design of Interpretable Fuzzy Controllers". In: *Foundations of Computing and Decision Sciences* 33.4 (2008), pp. 351–367. URL: http://www.framsticks.com/files/common/EvolveInterpretableFuzzyControl.pdf.

[HKW03] Maciej Hapke, Maciej Komosinski, and Dawid Waclawski. "Application of Evolutionarily Optimized Fuzzy Controllers for Virtual Robots". In: *Proceedings of the 7th Joint Conference on Information Sciences*. North Carolina, USA: Association for Intelligent Machinery, Sept. 2003, pp. 1605–1608. URL: http://www.framsticks.com/files/common/EvolvedFuzzyControl_CINC2003.pdf.