Evolution of Ideas: A Novel Memetic Algorithm Based on Semantic Networks

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1 Background
- Universal Darwinism
- Memetics

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- Initialization
- Fitness Measure
- Selection
- Variation

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Aims

Introducing a computational model of memetic evolution—of ideas, knowledge, or culture—using semantic networks as the representation scheme.
Aims

Three main contributions:

1. Using semantic networks for encoding *memotypes*
2. Introducing variation operators specific to semantic networks, utilizing *commonsense reasoning*
3. Introducing a memetic fitness measure based on *structure mapping theory* from psychology
Background
Universal Darwinism

Evolutionary processes are not restricted to living organisms and can be extended to systems beyond biology (Dennett 1995):

- Economics
- Psychology
- Physics
- Culture
Evolutionary algorithms (EA) simulate the progression of

- variation,
- natural selection,
- and heredity

to find novel solutions to problems in engineering and sciences.
As a *gene* is the unit of heredity in biological evolution,
a *meme* (Dawkins 1989) is the *unit of information in cultural evolution*
- hosted, altered, and reproduced in people’s minds

Memetic algorithms (MA) combine EA with individual learning to simulate the effect of learning on survival
The Algorithm
The Algorithm

- Based on “memes” undergoing variation, transmission, and selection under a fitness measure
- Evolving pieces of knowledge are represented as semantic networks
- Proceeds similar to a conventional EA cycle
Semantic networks represent individual pieces of knowledge as directed graphs of concepts and relations. Simple yet powerful means to represent the “memes” of Dawkins, allowing an implementation of memetics.
Allowable relations between concepts are restricted by *commonsense reasoning*

- i.e. **relations have to make sense to be useful**
  - \(IsA(bird, animal)\) is meaningful
  - while \(Causes(bird, table)\) is not
Commonsense reasoning is the type of reasoning involved in everyday thinking, “the knowledge of how the world works”
- e.g. “the sky is blue”, “a ball can roll”, “cats have four legs”

We use commonsense knowledge bases to ensure results from all operations on individual networks are meaningful
- MIT ConceptNet (560,000 relations and 320,000 concepts)
- WordNet (117,000 synsets)
Initialization

Population is initialized with individuals created by random semantic network generation:

1. Start from a single random concept
2. Attach a new concept through a new relation, randomly picked from knowledge bases, involving a random concept existing in the network
3. Repeat until a given network size is achieved
Fitness Measure

- Individuals in the population represent knowledge
- Therefore, fitness measure is defined as a function of represented knowledge
To evaluate the approach, we introduce a fitness measure based on analogical reasoning:

- Analogy is at the heart of human intellect (Holyoak and Thagard 1996):
  - Problem solving, perception, memory, creativity

- Extensively linked with creative thought in discoveries in arts and science:
  - Kepler’s explanation of planetary motion with an analogy to light radiating from Sun
  - Rutherford’s analogy between the atom and the Solar System
For evolving analogies, and analogous *target domains*, we define a fitness function

- based on analogical similarity score to a given *base domain*
- using **Structure Mapping Engine (SME) from psychology** (Falkenhainer, Forbus, and Gentner 1989)
Selection

After assigning fitness values to all individuals

- Members are replaced by offspring generated by variation operators on selected parents
- Selection is done randomly by *tournament selection*, favoring individuals with higher fitness
We introduce *commonsense crossover*, specific to semantic networks.

Two types that are tried in sequence:

- Type I (subgraph crossover)
- Type II (graph merging crossover)
Variation Operators (Crossover)

Type I (subgraph crossover), centered on the concepts of *bird* and *airplane*
Variation Operators (Crossover)

Type II (graph merging crossover), merging by relation \( \text{CreatedBy}(\text{art}, \text{human}) \)
Variation Operators (Mutation)

We introduce several types of *commonsense mutation*, picked randomly for each mutation event

- Type I (concept attachment)
- Type IIa (relation addition)
- Type IIb (relation deletion)
- Type IIIa (concept addition)
- Type IIIb (concept deletion)
- Type IV (concept replacement)
Variation Operators (Mutation)

Mutation Type I (concept attachment)

(h) Before

(i) After
Variation Operators (Mutation)

(j) Before

(k) After

Mutation Type IIa (relation addition)
Variation Operators (Mutation)

Mutation Type IIIb (concept deletion)
Variation Operators (Mutation)

(n) Before

(o) After

Mutation Type IV (concept replacement)
Examples
## Parameters

Parameters used during experiments

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Evolution</strong></td>
<td></td>
</tr>
<tr>
<td>Population size ($Pop_{size}$)</td>
<td>200</td>
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<tr>
<td>Crossover probability ($P_c$)</td>
<td>0.85</td>
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<tr>
<td>Mutation probability ($P_m$)</td>
<td>0.15</td>
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<tr>
<td><strong>Semantic networks</strong></td>
<td></td>
</tr>
<tr>
<td>Max. initial concepts ($C_{max}$)</td>
<td>5</td>
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<tr>
<td>Min. relation score ($R_{min}$)</td>
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<td>Timeout ($T$)</td>
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<tr>
<td><strong>Selection</strong></td>
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<tr>
<td>Tournament size ($S_{size}$)</td>
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</tr>
<tr>
<td>Tournament win prob. ($S_{prob}$)</td>
<td>0.8</td>
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<tr>
<td>Elitism</td>
<td>Employed</td>
</tr>
</tbody>
</table>
Solar System – Fruit

(p) Given network, 10 concepts, 11 relations (base domain)

(q) Evolved individual, 9 concepts, 9 relations (target domain)

Experiment 1: Encountered after 35 generations, fitness 2.8
(Parts not involved in analogy are not shown for clarity)
Family – Orchestra

(r) Given network, 11 concepts, 11 relations (base domain)

(s) Evolved individual, 10 concepts, 9 relations (target domain)

Experiment 2: Encountered after 42 generations, fitness 2.7
(Parts not involved in analogy are not shown for clarity)
Conclusions
We introduced **a novel algorithm employing semantic networks as evolving individuals**, the first of its kind

- Focused exclusively on the evolution of knowledge itself, under the fitness of represented knowledge
- Memetic variation operators utilizing commonsense knowledge
- Different from existing MA, where “memetic” is used to mean an hybridization of local refinement with generic EA
The tested fitness measure is capable of

- spontaneously generating semantic networks analogous to a given base
- open-ended creation of novel analogies together with analogous cases
  - Existing models only consider analogies between a given pair of cases
Conclusions

With other fitness measures, the algorithm can

- serve as a **generic tool for generating pieces of knowledge with any desired quantifiable property**
- enable simulations of selectionist theories of knowledge, which remain untested until this time

  - *Evolutionary epistemology* of Campbell (2003), describing creativity through *blind variation and selective retention* (*BVSR*)
  - *Cultural selection theory* (Crozier 2008)
References