Computational Modelling of Analogy and Blending for Scientific Creativity

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Outline
1) Analogical Reasoning
2) Computational Creativity
   – CSM & Ludi
   – Aris
3) Psychological Evidence
   – Dr Inventor project
4) Conclusions

1) Analogical Reasoning

• 3 major events in the study of analogy
• 1st major event
• Aristotle: Analogy is the mis-application of the name of one thing onto another
  – two-space model
• Example
  – “John is a pig”
  – Literal or analogical meaning

Non-literal Similarity

• Literal vs. Analogical similarity
• Find the equivalent of 1(a) in (b)?
• (Gentner and Smith, 2012)

Proportional Analogies

• A : B :: C : ?
  – Some unknown D
• a b c : a b d :: w x w z
• 1 : 2 :: 3 : ?   4 or 6
• 2 : 4 :: 3 : ?   5 or 9 (n^n)
• (Hofstadter & Mitchell, 1994)

Geometric Proportional Analogies

• Many simple GPA’s solved by T.G. Evans 1964/1967
  – Taking images as input
Structure Mapping Theory

- 2nd major event in analogy understanding
- Structure Mapping Theory - SMT (Dedre Gentner, 1983)
- An Analogy is a "deep" comparison between two different systems of information
- Interpreting an analogy is like matching two graphs

Comparing Collections of Information

- So, if Jim is like a pig:
  - then Jim's room is like a pig sty
  - and Jim's food is like pig-swill
  - and Jim's odour is like ...

  - Tom is like a pig - is an analogy
  - A pig is like a Tom - is also an analogy
  - One pig is like another pig - also not an analogy

"JFK's White house is like Camelot"s

- Camelot
- Guinevere
- Round Table
- Magic
- England
- Merlin
- Politics
- U.S.A.
- 1960's

Phases of Analogy

1. Representation
2. Retrieval
3. Structure Mapping
4. Validation
5. Induction

Analogical Transfer

Translate this extra information to the Target

Analogical Creativity

- "Workaday creativity" (Gardner 1993) or little-c creativity
  - Everyday or unremarkable creativity,
  - Writing code or documents,
  - Drawing a picture
  - Cooking
- 2 analogy-based computational models of workaday creativity
Computational Creativity

- Get computers to do similar things to human creativity
- Generate artefacts (images, poems etc) that have two essential properties (Boden, 1990)
  - **Novel**
    - New and different
  - **Quality** (useful)
    - As judged by experts

3 Levels of Creativity

- Creativity is often seen through the search space metaphor
  1. **Improbable (or Combinational)** - unfamiliar combinations of familiar ideas
  2. **Exploratory** – explore limits of existing conceptual space
  3. **Transformational** – deliberate transformation (transcend) of search space

Contextual Structure Mapping

- (Bohan & O’Donoghue, 2000; Mullally & O’Donoghue, 2006; O’Donoghue, Bohan & Keane, 2006)
- Consider GPA problem that include attributes
  - Colour, shading, patterns, orientation

\[ \begin{array}{cccc}
A & B & C & D \\
\end{array} \]
Topographic Maps
• Land-cover map with polygons identifying:
  – roads, buildings, footpaths (13 main categories)

Ludi
• Non-identical attributes requires increased flexibility
• Greater “creativity” required for some problems
  – More novel and potentially more useful

Aris
• Aris - Analogical Reasoning for Implementations and Specifications
• Similar implementations have similar specifications, facilitating re-use

Similar Implementation
```java
public static int Sum(int x)
{
    int add = 0;
    int k = 0;
    int irrelevantVariable = 0;
    Console.WriteLine(irrelevantVariable);
    while (k < x)
    {
        add += k;
        k = k-1;
        k = k +2;
    }
    return (int) add;
}
```

(O’Donoghue, Monahan et al., 214)
Analogous Code

- Find the analogical mapping between two code graphs
  - Implementation 1 and
  - Implementation 2
- Some constructs and variables are mapped, between two methods
- Finding analogous implementations should enable re-use of associated artefacts
  - Like formal specifications

Associated Specifications

```csharp
public static int Sum(int x)
{
    int add = 0;
    int k = 0;
    int irrelevantVariable = 0;
    Console.WriteLine(irrelevantVariable);
    while (k < x)
    {
        add += k; k = k-1; k = k +2;
    }
    return (int) add;
}
```

Analogies in Science

- Analogies have long been used to teach and summarise science.
- Novel analogies have even driven new scientific discoveries
    - Heart is like a pump
    - The eye is like a lens
    - Gas particles are like moving billiard balls
    - The atom is like the solar system
    - Light is like a wave
    - Light is like a particle
    - A computer network is like a mesh
    - The brain is like a computer
    - The brain is like a telephone network
    - The brain is like a network

Analogies for Time

- Most languages have future in front, present behind

```
Past
Future
```

- Either Time flows & we stay stationary, or we move and time stays stationary
- But the Aymara indian language is the opposite
  - (Nunez & Sweetzer, 2006)

Psychology Studies

- Tumour : Fortress analogy
- Analogous source analogy significantly improved solution rates
  - When hinted to use the analogy
    - (Gick and Holyoak, 1980)
- Target + 2 sources can result in the induction of a generalised “rule”
  - (Gick and Holyoak, 1983)

Scientists use analogies

- In 16 laboratory meetings in 4 laboratories
  - over 99 analogies identified
  - from 3 to 15 analogies in a one-hour meeting
  - mostly "within-domains" analogies
    - organism <-> other organism
  - "Creative" tasks used analogies between un-related topics
    - Eg formulating an hypothesis
    - (Dunbar and Blanchette, 2001)
Problems with Human Creativity

- Failure to Notice Analogies
  - Study: <20% of people notice analogies - even when they are present
- Overcome “Problem fixation”
  - By deliberately seeking inter-domain analogies (Goldschmidt, 2011)
- Memory limitations
  - Recalling analogs (long-term memory)
  - developing comparisons (working memory)

Conceptual Blending

- 3rd major event in the study of analogy is the introduction of Conceptual Blending
  - A 4 space model of analogy-like reasoning
- (Fauconnier and Turner, 1997)

2 Monks Problem

- “A Buddhist begins at dawn on day walking up and mountain, finally reaching the top at sunset. He meditates for several days and then beings his descent one dawn, reaching he bottom at sunset.
- Prove there is a place on this path which he occupies at the same hour of the day on the two separate journeys.”

4 Space Model vs. Analogy

Dr Inventor

- Discover un-noticed analogies between scientific publications
- Computer graphics for development and evaluation
- Aimed at supporting transformational creativity or Big-C Creativity in its users
  – FP7-ICT-2013.8.1, #611383
Dr Inventor

- Text processing
  - co-referent identification
  - detection of causal structures
- Graph generation and mapping
  - Analogy identification & evaluation
  - Analogical inference assessment
- Analogy presentation & visualisation

Dr Inventor uses

- Assess the level of creativity estimated for a document – compared the other documents in the corpus
- Creative suggestion
  - Dr Inventor recommends an analogous paper, with the potential to prompt creative insight in the user

“under the hood”

<table>
<thead>
<tr>
<th>Source Paper</th>
<th>Target Paper</th>
<th>Generic Space Relation</th>
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</thead>
<tbody>
<tr>
<td>scene</td>
<td>plane</td>
<td>artifact</td>
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<tr>
<td>capture</td>
<td>discover</td>
<td>make</td>
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<td>quality</td>
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<td>segment</td>
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<td>guide</td>
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<td>method</td>
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</table>

Paper Similarity View

- The spiral curve with function $r = a \theta$ is plotted.
- The similarity values are sorted in descending sequence.
- To scroll and zoom one can use the mouse wheel.
- To telescope on the selected area one can use the bottom-left triangle.

“Pdf View” - displays the various data categories by highlighting them on the original PDF, a viewer built with PDF.js and provided by Mozilla.

Users can read the original paper by accessing the text, fonts, graphics and other embedded elements on display, and can also print, download, and share the PDF.
Conclusion

• Analogical reasoning has been heavily studied in cognitive science
• Analogy is central to much of our reasoning processes
• Computational modelling both helped analogy research and also opens up new avenues for future research
• Analogy-based models like *Dr Inventor* hold great promise for creativity and creativity support