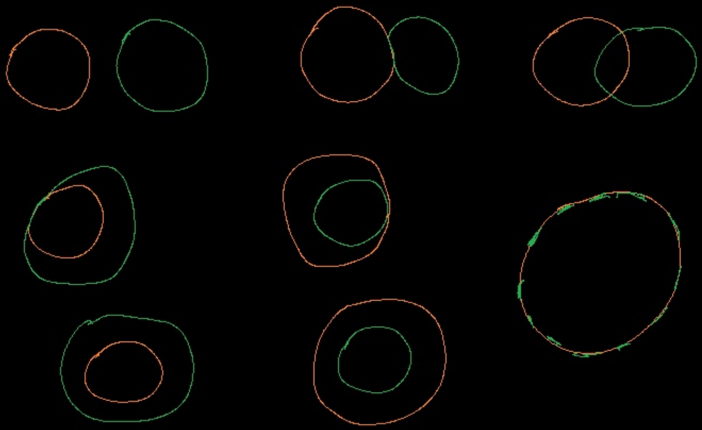
Case-Based Reasoning and Analogy: a Turbulent Love Story

Jean Lieber
Université de Lorraine, CNRS, Inria, LORIA, Nancy

ATA@ICCBR-2023

CBR and analogy: an RCC8 view



Overview

- Preliminaries:
  - Some definitions about CBR
  - Some definitions about analogy
- A subjective chronological viewpoint
- CBR examined from the viewpoint of proportional analogies
- Using analogical proportions for reasoning with cases
- Adaptation knowledge learning and analogy
- Is there a way to conclude this talk?

Preliminaries

Warning:

- To the CBR-ians: the first part is boring for you.
- To the analogists: the second part is boring for you.
- To all: please wake up after the preliminaries!

CBR (1/4)

What is a case?

- In all generality:
  a representation of a *problem-solving episode*

CBR (1/4)

What is a case?

- In all generality:
  a representation of a *problem-solving episode*
- *Problem-solving model*: a case is a pair (x, y) where
  - $x \in \mathcal{P}$
  - $y \in \mathcal{S}$
  - $x \rightsquigarrow y$ where $\rightsquigarrow$ reads "has for solution"

CBR (1/4)

What is a case?

- In all generality:
  a representation of a *problem-solving episode*
- *Problem-solution model*: a case is a pair (x, y) where
  - $\mathrm{x} \in \mathcal{P}$
  - $\mathrm{y} \in \mathcal{S}$
  - $\mathrm{x} \rightsquigarrow \mathrm{y}$ where $\rightsquigarrow$ reads "has for solution"
  - $\rightsquigarrow$ is usually uncompletely known by the CBR system, but known for *source cases* $(\mathrm{x}^s, \mathrm{y}^s) \in \mathrm{CB}$.

CBR (1/4)

What is a case?

- In all generality:
  a representation of a *problem-solving episode*
- *Problem-solution model*: a case is a pair (x, y) where
  - $\mathrm{x} \in \mathcal{P}$
  - $\mathrm{y} \in \mathcal{S}$
  - $\mathrm{x} \rightsquigarrow \mathrm{y}$ where $\rightsquigarrow$ reads "has for solution"
  - $\rightsquigarrow$ is usually uncompletely known by the CBR system, but known for *source cases* $(\mathrm{x}^s, \mathrm{y}^s) \in \mathrm{CB}$.
  - There may have additional information associated with $(\mathrm{x}^s, \mathrm{y}^s)$ (e.g. partial information about the reasoning process $\mathrm{x}^s \mapsto \mathrm{y}^s$).

CBR (1/4)

What is a case?

- In all generality:
  a representation of a *problem-solving episode*
- *Problem-solution model*: a case is a pair (x, y) where
  - $x \in \mathcal{P}$
  - $y \in \mathcal{S}$
  - $x \rightsquigarrow y$ where $\rightsquigarrow$ reads "has for solution"
  - $\rightsquigarrow$ is usually uncompletely known by the CBR system, but known for *source cases* $(x^s, y^s) \in \mathrm{CB}$.
  - There may have additional information associated with (x^s, y^s) (e.g. partial information about the reasoning process $x^s \mapsto y^s$).
- *Query-result model*: a case is an object (...)

CBR (1/4)

What is a case?

- In all generality:
  a representation of a *problem-solving episode*
- *Problem-solution model*: a case is a pair (x, y) where
  - $\mathrm{x} \in \mathcal{P}$
  - $\mathrm{y} \in \mathcal{S}$
  - $\mathrm{x} \leadsto \mathrm{y}$ where $\leadsto$ reads "has for solution"
  - $\leadsto$ is usually uncompletely known by the CBR system, but known for *source cases* $(\mathrm{x}^s, \mathrm{y}^s) \in \mathrm{CB}$.
  - There may have additional information associated with $(\mathrm{x}^s, \mathrm{y}^s)$ (e.g. partial information about the reasoning process $\mathrm{x}^s \mapsto \mathrm{y}^s$).
- *Query-result model*: a case is an object (...)
  - Target query: Q^{tgt}

CBR (1/4)

What is a case?

- In all generality:
  a representation of a *problem-solving episode*
- *Problem-solution model*: a case is a pair (x, y) where
  - $\mathrm{x} \in \mathcal{P}$
  - $\mathrm{y} \in \mathcal{S}$
  - $\mathrm{x} \leadsto \mathrm{y}$ where $\leadsto$ reads "has for solution"
  - $\leadsto$ is usually uncompletely known by the CBR system, but known for *source cases* $(\mathrm{x}^s, \mathrm{y}^s) \in \mathtt{CB}$.
  - There may have additional information associated with $(\mathrm{x}^s, \mathrm{y}^s)$ (e.g. partial information about the reasoning process $\mathrm{x}^s \mapsto \mathrm{y}^s$).
- *Query-result model*: a case is an object (...)
  - Target query: Q^{tgt}
  - If there is an exact match of a source case to the query: DB

CBR (1/4)

What is a case?

- In all generality:
  a representation of a *problem-solving episode*
- *Problem-solution model*: a case is a pair (x, y) where
  - $\mathrm{x} \in \mathcal{P}$
  - $\mathrm{y} \in \mathcal{S}$
  - $\mathrm{x} \rightsquigarrow \mathrm{y}$ where $\rightsquigarrow$ reads "has for solution"
  - $\rightsquigarrow$ is usually uncompletely known by the CBR system, but known for *source cases* $(\mathrm{x}^s, \mathrm{y}^s) \in \mathtt{CB}$.
  - There may have additional information associated with $(\mathrm{x}^s, \mathrm{y}^s)$ (e.g. partial information about the reasoning process $\mathrm{x}^s \mapsto \mathrm{y}^s$).
- *Query-result model*: a case is an object (...)
  - Target query: Q^{tgt}
  - If there is an exact match of a source case to the query: DB
  - Else, requires some inexact matching and adaptation.

CBR (2/4)

The process model: 2Rs from the 4Rs

x^{tgt}

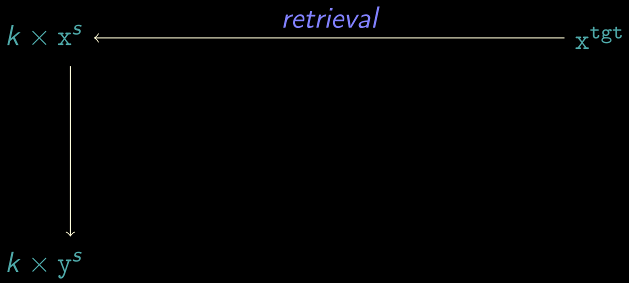
CBR (2/4)

The process model: 2Rs from the 4Rs

$$k \times \mathtt{x}^s \xleftarrow{\textit{retrieval}} \mathtt{x}^{\mathtt{tgt}}$$

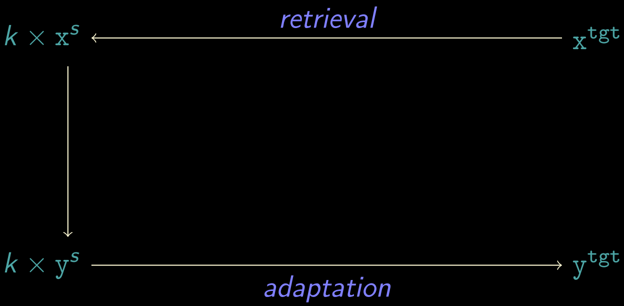
CBR (2/4)

The process model: 2Rs from the 4Rs



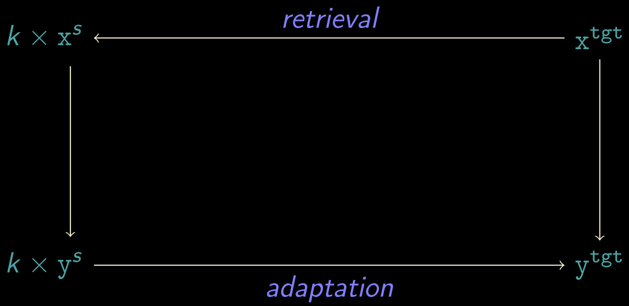
CBR (2/4)

The process model: 2Rs from the 4Rs



CBR (2/4)

The process model: 2Rs from the 4Rs



CBR (3/4)

The knowledge model: 4 knowledge containers

$$\text{CBR knowledge base} = \{\mathtt{CB}, \mathtt{DK}, \mathtt{AK}, \mathtt{RK}\}$$

- CB: the case base

CBR (3/4)

The knowledge model: 4 knowledge containers

$$\text{CBR knowledge base} = \{\texttt{CB}, \texttt{DK}, \texttt{AK}, \texttt{RK}\}$$

- CB: the case base
- DK: the domain knowledge (aka domain ontology)

CBR (3/4)

The knowledge model: 4 knowledge containers

$$\text{CBR knowledge base} = \{\mathtt{CB}, \mathtt{DK}, \mathtt{AK}, \mathtt{RK}\}$$

- CB: the case base
- DK: the domain knowledge (aka domain ontology)
  - Given x and y, DK gives necessary conditions for "y is a solution to the problem x".

CBR (3/4)

The knowledge model: 4 knowledge containers

$$\text{CBR knowledge base} = \{\mathtt{CB}, \mathtt{DK}, \mathtt{AK}, \mathtt{RK}\}$$

- CB: the case base
- DK: the domain knowledge (aka domain ontology)
  - Given x and y, DK gives necessary conditions for “y is a solution to the problem x”.
- AK: adaptation knowledge
  (e.g. adaptation rules)

CBR (3/4)

The knowledge model: 4 knowledge containers

$$\text{CBR knowledge base} = \{\mathtt{CB}, \mathtt{DK}, \mathtt{AK}, \mathtt{RK}\}$$

- $\mathtt{CB}$: the case base
- $\mathtt{DK}$: the domain knowledge (aka domain ontology)
  - Given $\mathtt{x}$ and $\mathtt{y}$, $\mathtt{DK}$ gives necessary conditions for "$\mathtt{y}$ is a solution to the problem $\mathtt{x}$".
- $\mathtt{AK}$: adaptation knowledge
  (e.g. adaptation rules)
- $\mathtt{RK}$: retrieval knowledge
  (e.g. distance function or similarity measure on $\mathcal{P}$)

CBR (4/4)

- Ian Watson has raised the question

  Is CBR a Technology or a Methodology?

  1998

CBR (4/4)

- Ian Watson has raised the question

  Is CBR a Technology or a Methodology?

  1998

- Ian's answer: a methodology

CBR (4/4)

- Ian Watson has raised the question

  Is CBR a Technology or a Methodology?

  1998

- Ian's answer: a methodology
- But that does not imply that all studies in CBR are methodological ones.

CBR (4/4)

- Ian Watson has raised the question

  Is CBR a Technology or a Methodology?

  1998

- Ian's answer: a methodology
- But that does not imply that all studies in CBR are methodological ones.
- There are some technological studies on CBR.

Analogy in this talk

- What is meant by "analogy" in this talk?

Analogy in this talk

- What is meant by "analogy" in this talk?
- Everything that is related to reasoning with a structure "a is to b as c is to d".

Analogy in this talk

- What is meant by "analogy" in this talk?
- Everything that is related to reasoning with a structure "a is to b as c is to d".
- No more.

Analogy in this talk

- What is meant by "analogy" in this talk?
- Everything that is related to reasoning with a structure "a is to b as c is to d".
- No more.
- No less.

Analogy in this talk

- What is meant by “analogy” in this talk?
- Everything that is related to reasoning with a structure “a is to b as c is to d”.
- No more.
- No less.
- In particular, analogical proportions.

Analogical proportions (1/4)

- A quaternary relation on a set $\mathcal{U}$ denoted by $a : b :: c : d$ and satisfying *some* postulates.

Analogical proportions (1/4)

- A quaternary relation on a set $\mathcal{U}$ denoted by $a : b :: c : d$ and satisfying *some* postulates.
- Intuition: $a : b :: c : d$ if what is similar/dissimilar from a to b is equivalent to what is similar/dissimilar from c to d

Analogical proportions (1/4)

- A quaternary relation on a set $\mathcal{U}$ denoted by $a:b::c:d$ and satisfying *some* postulates.
- Intuition: $a:b::c:d$ if what is similar/dissimilar from a to b is equivalent to what is similar/dissimilar from c to d
- $****$ postulates: the ones that seem to be universally accepted.
- $***$ postulates: widely accepted but under debate
- $**$ postulates: accepted by some analogists, rejected by others
- $*$ postulates: well...

Analogical proportions (1/4)

- A quaternary relation on a set $\mathcal{U}$ denoted by $a : b :: c : d$ and satisfying *some* postulates.
- Intuition: $a : b :: c : d$ if what is similar/dissimilar from a to b is equivalent to what is similar/dissimilar from c to d
- $\ast\ast\ast\ast$ postulates: the ones that seem to be universally accepted.
- $\ast\ast\ast$ postulates: widely accepted but under debate
- $\ast\ast$ postulates: accepted by some analogists, rejected by others
- $\ast$ postulates: well...
- According to who?

Analogical proportions (1/4)

- A quaternary relation on a set $\mathcal{U}$ denoted by $a:b::c:d$ and satisfying *some* postulates.
- Intuition: $a:b::c:d$ if what is similar/dissimilar from a to b is equivalent to what is similar/dissimilar from c to d
- $****$ postulates: the ones that seem to be universally accepted.
- $***$ postulates: widely accepted but under debate
- $**$ postulates: accepted by some analogists, rejected by others
- $*$ postulates: well...
- According to who?
- According to me. *But you can disagree!*

Analogical proportions (1/4)

- A quaternary relation on a set $\mathcal{U}$ denoted by $a : b :: c : d$ and satisfying *some* postulates.
- Intuition: $a : b :: c : d$ if what is similar/dissimilar from a to b is equivalent to what is similar/dissimilar from c to d
- $\ast\ast\ast\ast$ postulates: the ones that seem to be universally accepted.
- $\ast\ast\ast$ postulates: widely accepted but under debate
- $\ast\ast$ postulates: accepted by some analogists, rejected by others
- $\ast$ postulates: well...
- According to who?
- According to me.

But you can disagree!
(If you dare...)

Analogical proportions (2/4)

A set of non-independent postulates

- **** $a : b :: a : b$
- **** $a : a :: b : b$
- *** If $a : b :: a : x$ then $x = b$
- *** If $a : a :: b : x$ then $x = b$
- **** If $a : b :: c : d$ then $c : d :: a : b$
- *** If $a : b :: c : d$ then $a : c :: b : d$
- *** If $a : b :: c : d$ then $d : b :: c : a$
- ** If $a : b :: c : d$ and $c : d :: e : f$ then $a : b :: e : f$

Analogical proportions (3/4)

Analogical equations

- Given $a, b, c \in \mathcal{U}$ and a symbol y (called *unknown*): expression $a : b :: c : y$

Analogical proportions (3/4)

Analogical equations

- Given $a, b, c \in \mathcal{U}$ and a symbol y (called *unknown*):
  expression $a : b :: c : y$
- Solving $a : b :: c : y$:
  finding the set $\{d \in \mathcal{U} \mid a : b :: c : d\}$

Analogical proportions (3/4)

Analogical equations

- Given $a, b, c \in \mathcal{U}$ and a symbol y (called *unknown*): expression $a : b :: c : y$
- Solving $a : b :: c : y$:
  finding the set $\{d \in \mathcal{U} \mid a : b :: c : d\}$
- Depending on the analogical proportion,
  an analogical equation may have
  0, 1, more than 1 solution(s).

Analogical proportions (4/4)

Examples of analogical proportions

- Arithmetical analogical proportions:

$$a : b :: c : d \quad \text{if} \quad b - a = d - c$$

(parallelogram abdc)

Analogical proportions (4/4)

Examples of analogical proportions

- Arithmetical analogical proportions:

$$a : b :: c : d \quad \text{if} \quad b - a = d - c$$

(parallelogram abdc)

  - On $\mathbb{Z}$, $\mathbb{R}$, $\mathbb{R}^n$

Analogical proportions (4/4)

Examples of analogical proportions

- Arithmetical analogical proportions:

$$a : b :: c : d \quad \text{if} \quad b - a = d - c$$

(parallelogram abdc)

  - On $\mathbb{Z}$, $\mathbb{R}$, $\mathbb{R}^n$
  - More generally, on a commutative group $(G, +)$

Analogical proportions (4/4)

Examples of analogical proportions

- Arithmetical analogical proportions:

$$a:b::c:d \quad \text{if} \quad b-a=d-c$$

(parallelogram abdc)

  - On $\mathbb{Z}$, $\mathbb{R}$, $\mathbb{R}^n$
  - More generally, on a commutative group $(G,+)$
  - On $\mathbb{B}=\{0,1\}$ where $b-a\in\{-1,0,1\}$, on $\mathbb{B}^n$

Analogical proportions (4/4)

Examples of analogical proportions

- Arithmetical analogical proportions:

$$a : b :: c : d \quad \text{if} \quad b - a = d - c$$

(parallelogram abdc)

  - On $\mathbb{Z}$, $\mathbb{R}$, $\mathbb{R}^n$
  - More generally, on a commutative group $(G, +)$
  - On $\mathbb{B} = \{0, 1\}$ where $b - a \in \{-1, 0, 1\}$, on $\mathbb{B}^n$
- Yves Lepage's analogy on strings

A subjective chronological viewpoint

In the 1980s ($\simeq$)

In parallel:

- Childhood of CBR
  Ch. Riesbeck and R. G. Schank, *Inside Case-Based Reasoning*, 1989
  (MOPs, CHEF, etc.)

In the 1980s ($\simeq$)

In parallel:

- Childhood of CBR
  Ch. Riesbeck and R. G. Schank, *Inside Case-Based Reasoning*, 1989
  (MOPs, CHEF, etc.)
- Planning by analogy
  J. G. Carbonell 1983 (TA) and 1986 (DA)

In the 1980s ($\simeq$)

In parallel:

- Childhood of CBR
  Ch. Riesbeck and R. G. Schank, *Inside Case-Based Reasoning*, 1989
  (MOPs, CHEF, etc.)
- Planning by analogy
  J. G. Carbonell 1983 (TA) and 1986 (DA)
  - TA: transformational analogy

In the 1980s ($\simeq$)

In parallel:

- Childhood of CBR
  Ch. Riesbeck and R. G. Schank, *Inside Case-Based Reasoning*, 1989 (MOPs, CHEF, etc.)
- Planning by analogy
  J. G. Carbonell 1983 (TA) and 1986 (DA)
  - TA: transformational analogy
  - DA: derivational analogy

In the 1980s ($\simeq$)

In parallel:

- Childhood of CBR
  Ch. Riesbeck and R. G. Schank, *Inside Case-Based Reasoning*, 1989 (MOPs, CHEF, etc.)
- Planning by analogy
  J. G. Carbonell 1983 (TA) and 1986 (DA)
  - TA: transformational analogy
  - DA: derivational analogy
  - PhD thesis of Manuela Veloso (defense in 1993)

In the 1980s ($\simeq$)

In parallel:

- Childhood of CBR
  Ch. Riesbeck and R. G. Schank, *Inside Case-Based Reasoning*, 1989
  (MOPs, CHEF, etc.)
- Planning by analogy
  J. G. Carbonell 1983 (TA) and 1986 (DA)
  - TA: transformational analogy
  - DA: derivational analogy
  - PhD thesis of Manuela Veloso (defense in 1993)
    - Multiple case retrieval and adaptation

In the 1980s ($\simeq$)

In parallel:

- Childhood of CBR
  Ch. Riesbeck and R. G. Schank, *Inside Case-Based Reasoning*, 1989
  (MOPs, CHEF, etc.)
- Planning by analogy
  J. G. Carbonell 1983 (TA) and 1986 (DA)
  - TA: transformational analogy
  - DA: derivational analogy
  - PhD thesis of Manuela Veloso (defense in 1993)
    - Multiple case retrieval and adaptation
    - Footprinting the initial state
      $\rightarrow$ The similarity between $\mathtt{x}^s$ and $\mathtt{x}^{\mathtt{tgt}}$ should depend on $\mathtt{y}^s$.

In the 1980s ($\simeq$)

In parallel:

- Childhood of CBR
  Ch. Riesbeck and R. G. Schank, *Inside Case-Based Reasoning*, 1989
  (MOPs, CHEF, etc.)
- Planning by analogy
  J. G. Carbonell 1983 (TA) and 1986 (DA)
  - TA: transformational analogy
  - DA: derivational analogy
  - PhD thesis of Manuela Veloso (defense in 1993)
    - Multiple case retrieval and adaptation
    - Footprinting the initial state
      $\rightarrow$ The similarity between $\mathtt{x}^s$ and $\mathtt{x}^{\mathtt{tgt}}$ should depend on $\mathtt{y}^s$.
    - Shift in vocabulary:
      planning by analogy became case-based planning

In the 1980s ($\simeq$)

In parallel:

- Childhood of CBR
  Ch. Riesbeck and R. G. Schank, *Inside Case-Based Reasoning*, 1989
  (MOPs, CHEF, etc.)
- Planning by analogy
  J. G. Carbonell 1983 (TA) and 1986 (DA)
  - TA: transformational analogy
  - DA: derivational analogy
  - PhD thesis of Manuela Veloso (defense in 1993)
    - Multiple case retrieval and adaptation
    - Footprinting the initial state
      $\longrightarrow$ The similarity between x^s and x^{tgt} should depend on y^s.
    - Shift in vocabulary:
      planning by analogy became case-based planning
    - At that time, analogy $\simeq$ CBR

A chauvinist slide

- Late 1980s, a French group of researchers worked on analogy
  D. Coulon, J.-F. Boivieux, L. Bourrelly, L. Bruneau, E. Chouraqui, J.-M. David, C. R. Lu, M. Py, J. Savelli, B. Séroussi, C. Vrain, *Le raisonnement par analogie en intelligence artificielle*, 1990

A chauvinist slide

- Late 1980s, a French group of researchers worked on analogy
  D. Coulon, J.-F. Boivieux, L. Bourrelly, L. Bruneau, E. Chouraqui, J.-M. David, C. R. Lu, M. Py, J. Savelli, B. Séroussi, C. Vrain, *Le raisonnement par analogie en intelligence artificielle*, 1990
- Among the themes discussed in this group:
  inter-domain analogy vs *intra-domain analogy*

A chauvinist slide

- Late 1980s, a French group of researchers worked on analogy
  D. Coulon, J.-F. Boivieux, L. Bourrelly, L. Bruneau, E. Chouraqui, J.-M. David, C. R. Lu, M. Py, J. Savelli, B. Séroussi, C. Vrain, *Le raisonnement par analogie en intelligence artificielle*, 1990
- Among the themes discussed in this group:
  inter-domain analogy vs *intra-domain analogy*
  (a debatable distinction)

A chauvinist slide

- Late 1980s, a French group of researchers worked on analogy
  D. Coulon, J.-F. Boivieux, L. Bourrelly, L. Bruneau, E. Chouraqui, J.-M. David, C. R. Lu, M. Py, J. Savelli, B. Séroussi, C. Vrain, *Le raisonnement par analogie en intelligence artificielle*, 1990
- Among the themes discussed in this group:
  inter-domain analogy vs *intra-domain analogy*
  (a debatable distinction)
- 1993: first French workshop on CBR (*raisonnement à partir de cas*)

A chauvinist slide

- Late 1980s, a French group of researchers worked on analogy D. Coulon, J.-F. Boivieux, L. Bourrelly, L. Bruneau, E. Chouraqui, J.-M. David, C. R. Lu, M. Py, J. Savelli, B. Séroussi, C. Vrain, *Le raisonnement par analogie en intelligence artificielle*, 1990
- Among the themes discussed in this group:
  inter-domain analogy vs *intra-domain analogy*
  (a debatable distinction)
- 1993: first French workshop on CBR (*raisonnement à partir de cas*)
- Some acknowledgement at that time that

CBR = intra-domain analogy

A chauvinist slide

- Late 1980s, a French group of researchers worked on analogy
  D. Coulon, J.-F. Boivieux, L. Bourrelly, L. Bruneau, E. Chouraqui, J.-M. David, C. R. Lu, M. Py, J. Savelli, B. Séroussi, C. Vrain, *Le raisonnement par analogie en intelligence artificielle*, 1990
- Among the themes discussed in this group:
  inter-domain analogy vs *intra-domain analogy*
  (a debatable distinction)
- 1993: first French workshop on CBR (*raisonnement à partir de cas*)
- Some acknowledgement at that time that

$$\text{CBR} = \text{intra-domain analogy} \subsetneq \text{analogy}$$

Two parallel phenomena within the ICCBR community during the 1990s (subjective view)

adaptation   analogy@ICCBR

Two parallel phenomena within the ICCBR community during the 1990s (subjective view)

adaptation

adaptation

analogy@ICCBR

analogy@ICCBR

Two parallel phenomena within the ICCBR community during the 1990s (subjective view)

adaptation
adaptation
adaptation

analogy@ICCBR
analogy@ICCBR
analogy@ICCBR

Two parallel phenomena within the ICCBR community during the 1990s (subjective view)

adaptation
adaptation
adaptation
adaptation

analogy@ICCBR
analogy@ICCBR
analogy@ICCBR
analogy@ICCBR

Two parallel phenomena within the ICCBR community during the 1990s (subjective view)

adaptation

adaptation

adaptation

adaptation

adaptation

analogy@ICCBR

analogy@ICCBR

analogy@ICCBR

analogy@ICCBR

analogy@ICCBR

Two parallel phenomena within the ICCBR community during the 1990s (subjective view)

adaptation
adaptation
adaptation
adaptation
adaptation
adaptation

analogy@ICCBR
analogy@ICCBR
analogy@ICCBR
analogy@ICCBR
analogy@ICCBR
analogy@ICCBR

Two parallel phenomena within the ICCBR community during the 1990s (subjective view)

adaptation	analogy@ICCBR
adaptation	analogy@ICCBR
adaptation	analogy@ICCBR
adaptation	analogy@ICCBR
adaptation	analogy@ICCBR
adaptation	analogy@ICCBR
adaptation	analogy@ICCBR

Two parallel phenomena within the ICCBR community during the 1990s (subjective view)

adaptation
adaptation
adaptation
adaptation
adaptation
adaptation
adaptation
adaptation

analogy@ICCBR
analogy@ICCBR
analogy@ICCBR
analogy@ICCBR
analogy@ICCBR
analogy@ICCBR
analogy@ICCBR
analogy@ICCBR

Two parallel phenomena within the ICCBR community during the 1990s (subjective view)

adaptation

adaptation

adaptation

adaptation

adaptation

adaptation

adaptation

adaptation

adaptation

analogy@ICCBR

analogy@ICCBR

analogy@ICCBR

analogy@ICCBR

analogy@ICCBR

analogy@ICCBR

analogy@ICCBR

analogy@ICCBR

analogy@ICCBR

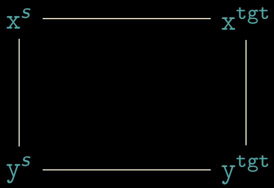
Two parallel phenomena within the ICCBR community during the 1990s (subjective view)

adaptation
adaptation
adaptation
adaptation
adaptation
adaptation
adaptation
adaptation
adaptation
adaptation

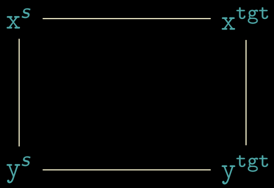
analogy@ICCBR
analogy@ICCBR
analogy@ICCBR
analogy@ICCBR
analogy@ICCBR
analogy@ICCBR
analogy@ICCBR
analogy@ICCBR
analogy@ICCBR
analogy@ICCBR

CBR examined from the viewpoint of proportional analogies

If $a:b::c:d$ then $a:c::b:d$

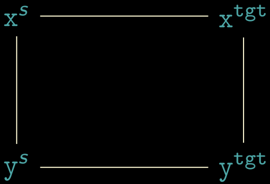


If $a : b :: c : d$ then $a : c :: b : d$



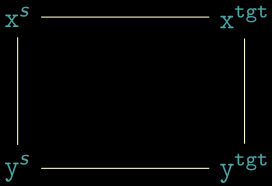
- Horizontal view: $x^s : x^{tgt} :: y^s : y^{tgt}$

If $a : b :: c : d$ then $a : c :: b : d$



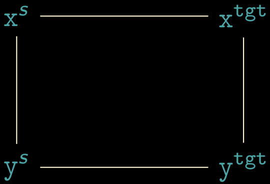
- Horizontal view: $x^s : x^{tgt} :: y^s : y^{tgt}$
  - TA

If $a : b :: c : d$ then $a : c :: b : d$



- Horizontal view: $\mathtt{x}^{s} : \mathtt{x}^{\mathtt{tgt}} :: \mathtt{y}^{s} : \mathtt{y}^{\mathtt{tgt}}$
  - TA
- Vertical view: $\mathtt{x}^{s} : \mathtt{y}^{s} :: \mathtt{x}^{\mathtt{tgt}} : \mathtt{y}^{\mathtt{tgt}}$

If $a : b :: c : d$ then $a : c :: b : d$



- Horizontal view: $x^s : x^{tgt} :: y^s : y^{tgt}$
  - TA
- Vertical view: $x^s : y^s :: x^{tgt} : y^{tgt}$
  - DA

Reflexivity-related postulates

	TA	DA

Reflexivity-related postulates

	TA	DA
$a : b :: a : b$	–	$\mathrm{x}^s : \mathrm{y}^s :: \mathrm{x}^s : \mathrm{y}^s$

Reflexivity-related postulates

	TA	DA
$a:b::a:b$	–	$\mathrm{x}^s:\mathrm{y}^s::\mathrm{x}^s:\mathrm{y}^s$
$a:a::b:b$	$\mathrm{x}^s:\mathrm{x}^s::\mathrm{y}^s:\mathrm{y}^s$	–

Reflexivity-related postulates

	TA	DA
$a : b :: a : b$	–	$\mathrm{x}^s : \mathrm{y}^s :: \mathrm{x}^s : \mathrm{y}^s$
$a : a :: b : b$	$\mathrm{x}^s : \mathrm{x}^s :: \mathrm{y}^s : \mathrm{y}^s$	–
if $a : b :: a : x$ then $x = b$	–	if $\mathrm{x}^s : \mathrm{y}^s :: \mathrm{x}^s : y$ then $y = \mathrm{y}^s$ (unicity of solution)

Reflexivity-related postulates

	TA	DA
$a : b :: a : b$	–	$\mathrm{x}^s : \mathrm{y}^s :: \mathrm{x}^s : \mathrm{y}^s$
$a : a :: b : b$	$\mathrm{x}^s : \mathrm{x}^s :: \mathrm{y}^s : \mathrm{y}^s$	–
if $a : b :: a : x$ then $x = b$	–	if $\mathrm{x}^s : \mathrm{y}^s :: \mathrm{x}^s : y$ then $y = \mathrm{y}^s$ (unicity of solution)
if $a : a :: b : x$ then $x = b$	if $\mathrm{x}^s : \mathrm{x}^s :: \mathrm{y}^s : y$ then $y = \mathrm{y}^s$ (unicity of solution)	–

If $a : b :: c : d$ and $c : d :: e : f$ then $a : b :: e : f$

Multi-step single adaptation using similarity paths and adaptation paths

x^{tgt}

If $a : b :: c : d$ and $c : d :: e : f$ then $a : b :: e : f$

Multi-step single adaptation using similarity paths and adaptation paths

$\mathtt{x}^{s}$ $\mathtt{x}^{\mathtt{tgt}}$

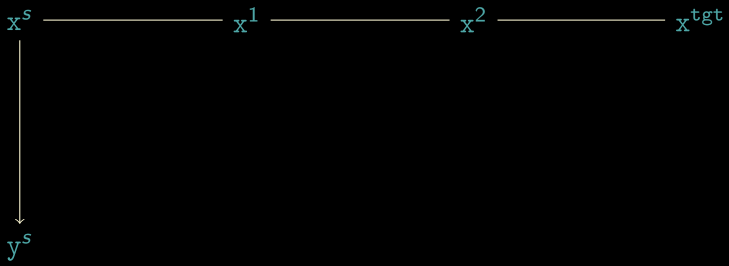
If $a : b :: c : d$ and $c : d :: e : f$ then $a : b :: e : f$

Multi-step single adaptation using similarity paths and adaptation paths

$$x^s \;\text{———}\; x^1 \;\text{———}\; x^2 \;\text{———}\; x^{tgt}$$

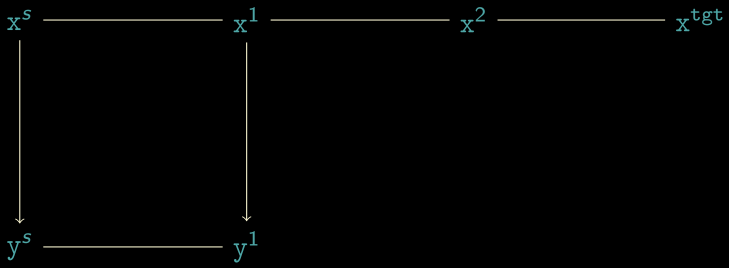
If $a : b :: c : d$ and $c : d :: e : f$ then $a : b :: e : f$

Multi-step single adaptation using similarity paths and adaptation paths



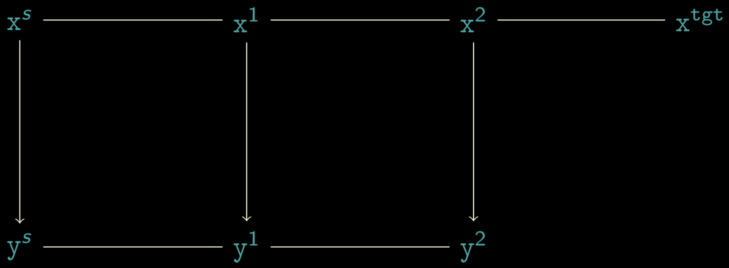
If $a : b :: c : d$ and $c : d :: e : f$ then $a : b :: e : f$

Multi-step single adaptation using similarity paths and adaptation paths



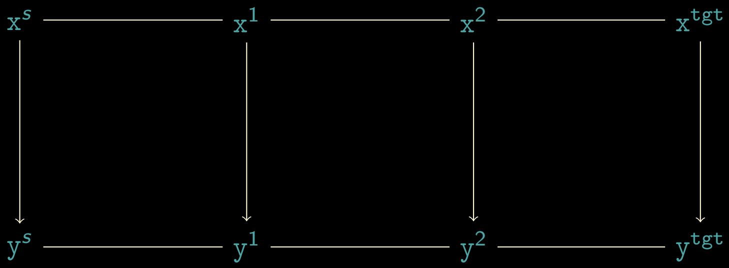
If $a:b::c:d$ and $c:d::e:f$ then $a:b::e:f$

Multi-step single adaptation using similarity paths and adaptation paths



If $a : b :: c : d$ and $c : d :: e : f$ then $a : b :: e : f$

Multi-step single adaptation using similarity paths and adaptation paths



Other postulates of proportional analogies considered from a CBR viewpoint

This is your homework.

Using analogical proportions for reasoning with cases

For $k = 1$: principle

- For some applications: $\mathcal{P} = \mathcal{S}$

For $k = 1$: principle

- For some applications: $\mathcal{P} = \mathcal{S}$
- For them, an analogical proportion on $\mathcal{P} = \mathcal{S} = \mathcal{U}$ does the job:

For $k = 1$: principle

- For some applications: $\mathcal{P} = \mathcal{S}$
- For them, an analogical proportion on $\mathcal{P} = \mathcal{S} = \mathcal{U}$ does the job:
  - Retrieval: select the $(\mathrm{x}^s, \mathrm{y}^s) \in \mathtt{CB}$ such that $\mathrm{x}^s : \mathrm{y}^s :: \mathrm{x}^{\mathtt{tgt}} : y$ is solvable

For $k = 1$: principle

- For some applications: $\mathcal{P} = \mathcal{S}$
- For them, an analogical proportion on $\mathcal{P} = \mathcal{S} = \mathcal{U}$ does the job:
  - Retrieval: select the $(\mathtt{x}^s, \mathtt{y}^s) \in \mathtt{CB}$ such that $\mathtt{x}^s : \mathtt{y}^s :: \mathtt{x}^{\mathtt{tgt}} : y$ is solvable
  - Solve the $\mathtt{x}^s : \mathtt{y}^s :: \mathtt{x}^{\mathtt{tgt}} : y$ equations and combine / vote

For $k = 1$: TFC

Lepage, Lieber, Mornard, Nauer, Romary, Sies, ICCBR-2020, *The French Correction: When Retrieval Is Harder to Specify than Adaptation*

- Using the analogical proportion (= proportional analogy?) of Yves [Lepage, Denoual, 2005]

For $k = 1$: TFC

Lepage, Lieber, Mornard, Nauer, Romary, Sies, ICCBR-2020, *The French Correction: When Retrieval Is Harder to Specify than Adaptation*

- Using the analogical proportion ($=$ proportional analogy?) of Yves [Lepage, Denoual, 2005]
- An English example:

$$\begin{aligned} \mathtt{x}^{s} &= \\ \mathtt{y}^{s} &= \\ \mathtt{x}^{\mathtt{tgt}} &= \\ \mathtt{y}^{\mathtt{tgt}} &= \end{aligned}$$

For $k = 1$: TFC

Lepage, Lieber, Mornard, Nauer, Romary, Sies, ICCBR-2020, *The French Correction: When Retrieval Is Harder to Specify than Adaptation*

- Using the analogical proportion ($=$ proportional analogy?) of Yves [Lepage, Denoual, 2005]
- An English example:

$$\begin{aligned} \mathtt{x}^{s} &= \\ \mathtt{y}^{s} &= \\ \mathtt{x}^{\mathtt{tgt}} &= \textit{Fadi will going to Aberdeen.} \\ \mathtt{y}^{\mathtt{tgt}} &= \end{aligned}$$

For $k = 1$: TFC

Lepage, Lieber, Mornard, Nauer, Romary, Sies, ICCBR-2020, *The French Correction: When Retrieval Is Harder to Specify than Adaptation*

- Using the analogical proportion (= proportional analogy?) of Yves [Lepage, Denoual, 2005]
- An English example:

$$
\begin{aligned}
\mathtt{x}^s &= \textit{Miguel would not eating his soup.}\\
\mathtt{y}^s &= \\
\mathtt{x}^{\mathtt{tgt}} &= \textit{Fadi will going to Aberdeen.}\\
\mathtt{y}^{\mathtt{tgt}} &=
\end{aligned}
$$

For $k = 1$: TFC

Lepage, Lieber, Mornard, Nauer, Romary, Sies, ICCBR-2020, *The French Correction: When Retrieval Is Harder to Specify than Adaptation*

- Using the analogical proportion (= proportional analogy?) of Yves [Lepage, Denoual, 2005]
- An English example:

$$
\begin{aligned}
\mathtt{x}^s &= \textit{Miguel would not eating his soup.} \\
\mathtt{y}^s &= \textit{Miguel would not eat his soup.} \\
\mathtt{x}^{\mathtt{tgt}} &= \textit{Fadi will going to Aberdeen.} \\
\mathtt{y}^{\mathtt{tgt}} &=
\end{aligned}
$$

For $k = 1$: TFC

Lepage, Lieber, Mornard, Nauer, Romary, Sies, ICCBR-2020, *The French Correction: When Retrieval Is Harder to Specify than Adaptation*

- Using the analogical proportion (= proportional analogy?) of Yves [Lepage, Denoual, 2005]
- An English example:

$$
\begin{aligned}
\mathtt{x}^s &= \textit{Miguel would not eating his soup.} \\
\mathtt{y}^s &= \textit{Miguel would not eat his soup.} \\
\mathtt{x}^{\mathtt{tgt}} &= \textit{Fadi will going to Aberdeen.} \\
\mathtt{y}^{\mathtt{tgt}} &= \textit{Fadi will go to Aberdeen.}
\end{aligned}
$$

For $k = 1$: TFC

Lepage, Lieber, Mornard, Nauer, Romary, Sies, ICCBR-2020, *The French Correction: When Retrieval Is Harder to Specify than Adaptation*

- Using the analogical proportion (= proportional analogy?) of Yves [Lepage, Denoual, 2005]
- An English example:

$$\begin{aligned} \mathtt{x}^s &= \textit{Miguel would not eating his soup.} \\ \mathtt{y}^s &= \textit{Miguel would not eat his soup.} \\ \mathtt{x}^{\mathtt{tgt}} &= \textit{Fadi will going to Aberdeen.} \\ \mathtt{y}^{\mathtt{tgt}} &= \textit{Fadi will go to Aberdeen.} \end{aligned}$$

- For this example: adaptation is simple, retrieval is harder...

For $k = 1$: TFC

Lepage, Lieber, Mornard, Nauer, Romary, Sies, ICCBR-2020, *The French Correction: When Retrieval Is Harder to Specify than Adaptation*

- Using the analogical proportion (= proportional analogy?) of Yves [Lepage, Denoual, 2005]
- An English example:

$$
\begin{aligned}
\mathtt{x}^{s} &= \textit{Miguel would not eating his soup.}\\
\mathtt{y}^{s} &= \textit{Miguel would not eat his soup.}\\
\mathtt{x}^{\mathtt{tgt}} &= \textit{Fadi will going to Aberdeen.}\\
\mathtt{y}^{\mathtt{tgt}} &= \textit{Fadi will go to Aberdeen.}
\end{aligned}
$$

- For this example: adaptation is simple, retrieval is harder...
- Lot of work to do to improve this application...
  (May be a challenge?)

For $k = 1$: Correcting image segmentation

Duck, Schaller, Auber, Chaussy, Henriet, Lieber, Nauer, Prade, ICCBR-2022,
Analogy-based post-treatment of CNN image segmentations

x^s

For $k = 1$: Correcting image segmentation

Duck, Schaller, Auber, Chaussy, Henriet, Lieber, Nauer, Prade, ICCBR-2022,
Analogy-based post-treatment of CNN image segmentations

x^s y^s

For $k = 1$: Correcting image segmentation

Duck, Schaller, Auber, Chaussy, Henriet, Lieber, Nauer, Prade, ICCBR-2022, *Analogy-based post-treatment of CNN image segmentations*

$\mathtt{x}^s$ $\mathtt{y}^s$ $\mathtt{x}^{\mathtt{tgt}}$

For $k = 1$: Correcting image segmentation

Duck, Schaller, Auber, Chaussy, Henriet, Lieber, Nauer, Prade, ICCBR-2022,
Analogy-based post-treatment of CNN image segmentations

$\mathtt{x}^s$ $\mathtt{y}^s$ $\mathtt{x}^{\mathtt{tgt}}$ $\mathtt{y}^{\mathtt{tgt}}$

For $k = 1$: Correcting image segmentation

Duck, Schaller, Auber, Chaussy, Henriet, Lieber, Nauer, Prade, ICCBR-2022,
Analogy-based post-treatment of CNN image segmentations

$\mathtt{x}^{s}$ $\mathtt{y}^{s}$ $\mathtt{x}^{\mathtt{tgt}}$ $\mathtt{y}^{\mathtt{tgt}}$ $\mathtt{expert}^{\mathtt{tgt}}$

For $k = 3$: principle

- Analogical extrapolation:

$$\frac{\mathtt{x}^a : \mathtt{x}^b :: \mathtt{x}^c : \mathtt{x}^{\mathtt{tgt}}}{\quad}$$

For $k = 3$: principle

- Analogical extrapolation:

$$\frac{\mathtt{x}^a : \mathtt{x}^b :: \mathtt{x}^c : \mathtt{x}^{\mathtt{tgt}}}{\mathtt{y}^a : \mathtt{y}^b :: \mathtt{y}^c : \mathtt{y}^{\mathtt{tgt}}}$$

For $k = 3$: principle

- Analogical extrapolation:

$$\frac{\mathtt{x}^a : \mathtt{x}^b :: \mathtt{x}^c : \mathtt{x}^{\mathtt{tgt}}}{\mathtt{y}^a : \mathtt{y}^b :: \mathtt{y}^c : \mathtt{y}^{\mathtt{tgt}}}$$

- Requires two analogical proportions: on $\mathcal{P}$ and on $\mathcal{S}$

For $k = 3$: principle

- Analogical extrapolation:

$$\frac{\mathrm{x}^a : \mathrm{x}^b :: \mathrm{x}^c : \mathrm{x}^{\mathtt{tgt}}}{\mathrm{y}^a : \mathrm{y}^b :: \mathrm{y}^c : \mathrm{y}^{\mathtt{tgt}}}$$

- Requires two analogical proportions: on $\mathcal{P}$ and on $\mathcal{S}$
- Retrieval: find $(\mathrm{x}^a, \mathrm{y}^a), (\mathrm{x}^b, \mathrm{y}^b), (\mathrm{x}^c, \mathrm{y}^c) \in \mathtt{CB}$ such that $\mathrm{x}^a : \mathrm{x}^b :: \mathrm{x}^c : \mathrm{x}^{\mathtt{tgt}}$

For $k = 3$: principle

- Analogical extrapolation:

$$\frac{\mathtt{x}^a : \mathtt{x}^b :: \mathtt{x}^c : \mathtt{x}^{\mathtt{tgt}}}{\mathtt{y}^a : \mathtt{y}^b :: \mathtt{y}^c : \mathtt{y}^{\mathtt{tgt}}}$$

- Requires two analogical proportions: on $\mathcal{P}$ and on $\mathcal{S}$
- Retrieval: find $(\mathtt{x}^a, \mathtt{y}^a), (\mathtt{x}^b, \mathtt{y}^b), (\mathtt{x}^c, \mathtt{y}^c) \in \mathtt{CB}$ such that $\mathtt{x}^a : \mathtt{x}^b :: \mathtt{x}^c : \mathtt{x}^{\mathtt{tgt}}$
- Adaptation: solve the equations $\mathtt{y}^a : \mathtt{y}^b :: \mathtt{y}^c : y$ (and combine solutions, or vote, if there are several solvable equations)

For $k = 3$: principle

- Analogical extrapolation:

$$\frac{\mathtt{x}^a : \mathtt{x}^b :: \mathtt{x}^c : \mathtt{x}^{\mathtt{tgt}}}{\mathtt{y}^a : \mathtt{y}^b :: \mathtt{y}^c : \mathtt{y}^{\mathtt{tgt}}}$$

- Requires two analogical proportions: on $\mathcal{P}$ and on $\mathcal{S}$
- Retrieval: find $(\mathtt{x}^a, \mathtt{y}^a), (\mathtt{x}^b, \mathtt{y}^b), (\mathtt{x}^c, \mathtt{y}^c) \in \mathtt{CB}$ such that $\mathtt{x}^a : \mathtt{x}^b :: \mathtt{x}^c : \mathtt{x}^{\mathtt{tgt}}$
- Adaptation: solve the equations $\mathtt{y}^a : \mathtt{y}^b :: \mathtt{y}^c : y$ (and combine solutions, or vote, if there are several solvable equations)
- For arithmetical analogical proportions, retrieval can be implemented efficiently thanks to an offline storage of $\mathtt{x}^b - \mathtt{x}^a$ in a database.

For $k = 3$: case-based translation in 2005

Yves Lepage and Étienne Denoual, *Purest ever example-based machine translation: Detailed presentation and assessment*, Machine Translation, 2005

- $\mathrm{x} \in \mathcal{P}$: sentence in an origin language (e.g. French)
  $\mathrm{y} \in \mathcal{S}$: sentence in a destination language (e.g. English)
  $\mathrm{x} \rightsquigarrow \mathrm{y}$: x can be translated into y

For $k = 3$: case-based translation in 2005

Yves Lepage and Étienne Denoual, *Purest ever example-based machine translation: Detailed presentation and assessment*, Machine Translation, 2005

- $\mathrm{x} \in \mathcal{P}$: sentence in an origin language (e.g. French)
  $\mathrm{y} \in \mathcal{S}$: sentence in a destination language (e.g. English)
  $\mathrm{x} \rightsquigarrow \mathrm{y}$: x can be translated into y
- Example:

$$
\begin{aligned}
\mathrm{x}^a &= \\
\mathrm{x}^b &= \\
\mathrm{x}^c &= \\
\mathrm{x}^{\mathrm{tgt}} &= \\
\mathrm{y}^a &= \\
\mathrm{y}^b &= \\
\mathrm{y}^c &= \\
\mathrm{y}^{\mathrm{tgt}} &=
\end{aligned}
$$

For $k = 3$: case-based translation in 2005

Yves Lepage and Étienne Denoual, *Purest ever example-based machine translation: Detailed presentation and assessment*, Machine Translation, 2005

- $\mathrm{x} \in \mathcal{P}$: sentence in an origin language (e.g. French)
  $\mathrm{y} \in \mathcal{S}$: sentence in a destination language (e.g. English)
  $\mathrm{x} \rightsquigarrow \mathrm{y}$: x can be translated into y
- Example:

$$
\begin{aligned}
\mathrm{x}^a &= \\
\mathrm{x}^b &= \\
\mathrm{x}^c &= \\
\mathrm{x}^{\mathrm{tgt}} &= \textit{Je veux faire du vélo.} \\
\mathrm{y}^a &= \\
\mathrm{y}^b &= \\
\mathrm{y}^c &= \\
\mathrm{y}^{\mathrm{tgt}} &=
\end{aligned}
$$

For $k = 3$: case-based translation in 2005

Yves Lepage and Étienne Denoual, *Purest ever example-based machine translation: Detailed presentation and assessment*, Machine Translation, 2005

- $\mathrm{x} \in \mathcal{P}$: sentence in an origin language (e.g. French)
  $\mathrm{y} \in \mathcal{S}$: sentence in a destination language (e.g. English)
  $\mathrm{x} \rightsquigarrow \mathrm{y}$: x can be translated into y
- Example:

$$
\begin{aligned}
\mathrm{x}^a &= \textit{Tu peux le faire aujourd'hui.} \\
\mathrm{x}^b &= \textit{Tu veux le faire.} \\
\mathrm{x}^c &= \textit{Je peux faire du vélo aujourd'hui.} \\
\mathrm{x}^{\mathrm{tgt}} &= \textit{Je veux faire du vélo.} \\
\mathrm{y}^a &= \\
\mathrm{y}^b &= \\
\mathrm{y}^c &= \\
\mathrm{y}^{\mathrm{tgt}} &=
\end{aligned}
$$

For $k = 3$: case-based translation in 2005

Yves Lepage and Étienne Denoual, *Purest ever example-based machine translation: Detailed presentation and assessment*, Machine Translation, 2005

- $\mathrm{x} \in \mathcal{P}$: sentence in an origin language (e.g. French)
  $\mathrm{y} \in \mathcal{S}$: sentence in a destination language (e.g. English)
  $\mathrm{x} \rightsquigarrow \mathrm{y}$: x can be translated into y
- Example:

$$
\begin{aligned}
\mathrm{x}^a &= \textit{Tu peux le faire aujourd'hui.} \\
\mathrm{x}^b &= \textit{Tu veux le faire.} \\
\mathrm{x}^c &= \textit{Je peux faire du vélo aujourd'hui.} \\
\mathrm{x}^{\mathrm{tgt}} &= \textit{Je veux faire du vélo.} \\
\mathrm{y}^a &= \textit{You can do it today.} \\
\mathrm{y}^b &= \textit{You want to do it.} \\
\mathrm{y}^c &= \textit{I can ride my bicycle today.} \\
\mathrm{y}^{\mathrm{tgt}} &=
\end{aligned}
$$

For $k = 3$: case-based translation in 2005

Yves Lepage and Étienne Denoual, *Purest ever example-based machine translation: Detailed presentation and assessment*, Machine Translation, 2005

- $\mathrm{x} \in \mathcal{P}$: sentence in an origin language (e.g. French)
  $\mathrm{y} \in \mathcal{S}$: sentence in a destination language (e.g. English)
  $\mathrm{x} \rightsquigarrow \mathrm{y}$: x can be translated into y
- Example:

$$
\begin{aligned}
\mathrm{x}^a &= \textit{Tu peux le faire aujourd'hui.} \\
\mathrm{x}^b &= \textit{Tu veux le faire.} \\
\mathrm{x}^c &= \textit{Je peux faire du vélo aujourd'hui.} \\
\mathrm{x}^{\mathtt{tgt}} &= \textit{Je veux faire du vélo.} \\
\mathrm{y}^a &= \textit{You can do it today.} \\
\mathrm{y}^b &= \textit{You want to do it.} \\
\mathrm{y}^c &= \textit{I can ride my bicycle today.} \\
\mathrm{y}^{\mathtt{tgt}} &= \textit{I want to ride my bicycle.}
\end{aligned}
$$

For $k = 3$: case-based translation in 2005

Yves Lepage and Étienne Denoual, *Purest ever example-based machine translation: Detailed presentation and assessment*, Machine Translation, 2005

- $\mathrm{x} \in \mathcal{P}$: sentence in an origin language (e.g. French)
  $\mathrm{y} \in \mathcal{S}$: sentence in a destination language (e.g. English)
  $\mathrm{x} \leadsto \mathrm{y}$: x can be translated into y
- Example:

$$
\begin{aligned}
\mathrm{x}^a &= \textit{Tu peux le faire aujourd'hui.}\\
\mathrm{x}^b &= \textit{Tu veux le faire.}\\
\mathrm{x}^c &= \textit{Je peux faire du vélo aujourd'hui.}\\
\mathrm{x}^{\mathrm{tgt}} &= \textit{Je veux faire du vélo.}\\
\mathrm{y}^a &= \textit{You can do it today.}\\
\mathrm{y}^b &= \textit{You want to do it.}\\
\mathrm{y}^c &= \textit{I can ride my bicycle today.}\\
\mathrm{y}^{\mathrm{tgt}} &= \textit{I want to ride my bicycle.}
\end{aligned}
$$

- [Lepage and Lieber, ICCBR-2018]: (1) recognizing this contribution as a knowledge-light CBR system (2) See how it might be improved into a knowledge-intensive CBR system

For $k = 3$: work with Emmanuel Nauer, Henri Prade and Gilles Richard

@ICCBR-2018 Theoretical and empirical study of
approximation ($k = 1$),
interpolation ($k = 2$) and
extrapolation ($k = 3$)

For $k = 3$: work with Emmanuel Nauer, Henri Prade and Gilles Richard

@ICCBR-2018 Theoretical and empirical study of
approximation ($k = 1$),
interpolation ($k = 2$) and
extrapolation ($k = 3$)

@ICCBR-2019 Competence of pairs of cases (based on support and confidence)
to improve analogical extrapolation

For $k = 3$: work with Emmanuel Nauer, Henri Prade and Gilles Richard

@ICCBR-2018 Theoretical and empirical study of
approximation ($k = 1$),
interpolation ($k = 2$) and
extrapolation ($k = 3$)

@ICCBR-2019 Competence of pairs of cases (based on support and confidence)
to improve analogical extrapolation

@ICCBR-2021 When Revision-Based Case Adaptation Meets Analogical Extrapolation

For $k = 3$: case-based cleaning

Éric Astier, Hugo Iopeti, Jean Lieber, Hugo Mathieu Steinbach, Ludovic Yvoz,
Case-Based Cleaning of Text Images, ICCBR-2023

- $\mathrm{x} \in \mathcal{P}$: image of a French text (from 19*th* or 20*th* century)
  $\mathrm{y} \in \mathcal{S}$: parameter triple of a cleaning filter
  $\mathrm{x} \rightsquigarrow \mathrm{y}$: the cleaning of x with parameter triple y gives satisfying results

For $k = 3$: case-based cleaning

Éric Astier, Hugo Iopeti, Jean Lieber, Hugo Mathieu Steinbach, Ludovic Yvoz, *Case-Based Cleaning of Text Images*, ICCBR-2023

- $\mathrm{x} \in \mathcal{P}$: image of a French text (from $19th$ or $20th$ century)
  $\mathrm{y} \in \mathcal{S}$: parameter triple of a cleaning filter
  $\mathrm{x} \rightsquigarrow \mathrm{y}$: the cleaning of x with parameter triple y gives satisfying results
- Approaches based on:
  - Approximation ($k = 1$)
  - Interpolation ($k = 2$)
  - Extrapolation ($k = 3$)

For $k = 3$: case-based cleaning

Éric Astier, Hugo Iopeti, Jean Lieber, Hugo Mathieu Steinbach, Ludovic Yvoz, *Case-Based Cleaning of Text Images*, ICCBR-2023

- $\mathrm{x} \in \mathcal{P}$: image of a French text (from $19th$ or $20th$ century)
  $\mathrm{y} \in \mathcal{S}$: parameter triple of a cleaning filter
  $\mathrm{x} \rightsquigarrow \mathrm{y}$: the cleaning of x with parameter triple y gives satisfying results
- Approaches based on:
  - Approximation ($k = 1$)
  - Interpolation ($k = 2$)
  - Extrapolation ($k = 3$)
- Talk on Thursday!

Adaptation knowledge learning and analogical extrapolation

Adaptation Knowledge Learning (AKL)

- Seminal paper of M. T. Keane and K. Hanney (EWCBR-96) many contributors to AKL *(I have started a list, but it is better to have an empty list then a nonempty incomplete liste)*

Adaptation Knowledge Learning (AKL)

- Seminal paper of M. T. Keane and K. Hanney (EWCBR-96)
  many contributors to AKL *(I have started a list, but it is better to have an empty list then a nonempty incomplete liste)*
- The *difference heuristics*
  (term borrowed to David Leake)

Adaptation Knowledge Learning (AKL)

- Seminal paper of M. T. Keane and K. Hanney (EWCBR-96) many contributors to AKL *(I have started a list, but it is better to have an empty list then a nonempty incomplete liste)*
- The *difference heuristics* (term borrowed to David Leake)
  - From $(x^i, y^i), (x^j, y^j)$ two different source cases:
    - $(x^i, x^j) \mapsto \Delta x^{ij}$ (in some problem difference formalism)
    - $(y^i, y^j) \mapsto \Delta y^{ij}$ (in some solution difference formalism)

Adaptation Knowledge Learning (AKL)

- Seminal paper of M. T. Keane and K. Hanney (EWCBR-96) many contributors to AKL *(I have started a list, but it is better to have an empty list then a nonempty incomplete liste)*
- The *difference heuristics* (term borrowed to David Leake)
  - From $(x^i, y^i), (x^j, y^j)$ two different source cases:
    - $(x^i, x^j) \mapsto \Delta x^{ij}$ (in some problem difference formalism)
    - $(y^i, y^j) \mapsto \Delta y^{ij}$ (in some solution difference formalism)
  - $\mathsf{AKL} : \left\{\left(\Delta x^{ij}, \Delta y^{ij}\right)\right\}_{ij} \mapsto \mathtt{AK}$

AKL with Boolean tuple representation of cases

Generalizable to attribute-value pairs

- For $\mathcal{D} = \{\texttt{=}1, \texttt{=}0, \texttt{+}, \texttt{-}\}$

$$
\begin{aligned}
x^i &= x_1 \wedge \neg x_2 \wedge \neg x_3 \wedge x_4 \\
x^j &= x_1 \wedge \neg x_2 \wedge x_3 \wedge \neg x_4
\end{aligned}
$$

AKL with Boolean tuple representation of cases

Generalizable to attribute-value pairs

- For $\mathcal{D} = \{\texttt{=1}, \texttt{=0}, \texttt{+}, \texttt{-}\}$

$$
\begin{aligned}
\mathrm{x}^i &= \mathrm{x}_1 \wedge \neg\mathrm{x}_2 \wedge \neg\mathrm{x}_3 \wedge \mathrm{x}_4 \\
\mathrm{x}^j &= \mathrm{x}_1 \wedge \neg\mathrm{x}_2 \wedge \mathrm{x}_3 \wedge \neg\mathrm{x}_4 \\
\Delta\mathrm{x}^{ij} &=
\end{aligned}
$$

AKL with Boolean tuple representation of cases

Generalizable to attribute-value pairs

- For $\mathcal{D} = \{\texttt{=1}, \texttt{=0}, \texttt{+}, \texttt{-}\}$

$$
\begin{aligned}
\mathrm{x}^i &= \mathrm{x}_1 \wedge \neg\mathrm{x}_2 \wedge \neg\mathrm{x}_3 \wedge \mathrm{x}_4 \\
\mathrm{x}^j &= \mathrm{x}_1 \wedge \neg\mathrm{x}_2 \wedge \mathrm{x}_3 \wedge \neg\mathrm{x}_4 \\
\Delta\mathrm{x}^{ij} &= \mathrm{x}_1^{\texttt{=1}}
\end{aligned}
$$

AKL with Boolean tuple representation of cases

Generalizable to attribute-value pairs

- For $\mathcal{D} = \{\texttt{=1}, \texttt{=0}, \texttt{+}, \texttt{-}\}$

$$\begin{array}{ccccccccc} \mathrm{x}^i & = & \mathrm{x}_1 & \wedge & \neg\mathrm{x}_2 & \wedge & \neg\mathrm{x}_3 & \wedge & \mathrm{x}_4 \\ \mathrm{x}^j & = & \mathrm{x}_1 & \wedge & \neg\mathrm{x}_2 & \wedge & \mathrm{x}_3 & \wedge & \neg\mathrm{x}_4 \\ \Delta\mathrm{x}^{ij} & = & \mathrm{x}_1^{=1} & \wedge & \mathrm{x}_2^{=0} & & & & \end{array}$$

AKL with Boolean tuple representation of cases

Generalizable to attribute-value pairs

- For $\mathcal{D} = \{\mathtt{=1}, \mathtt{=0}, \mathtt{+}, \mathtt{-}\}$

$$\begin{array}{rclllllll} \mathrm{x}^{i} & = & \mathrm{x}_1 & \wedge & \neg\mathrm{x}_2 & \wedge & \neg\mathrm{x}_3 & \wedge & \mathrm{x}_4 \\ \mathrm{x}^{j} & = & \mathrm{x}_1 & \wedge & \neg\mathrm{x}_2 & \wedge & \mathrm{x}_3 & \wedge & \neg\mathrm{x}_4 \\ \Delta\mathrm{x}^{ij} & = & \mathrm{x}_1^{\mathtt{=1}} & \wedge & \mathrm{x}_2^{\mathtt{=0}} & \wedge & \mathrm{x}_3^{\mathtt{+}} & & \end{array}$$

AKL with Boolean tuple representation of cases

Generalizable to attribute-value pairs

- For $\mathcal{D} = \{\texttt{=1}, \texttt{=0}, \texttt{+}, \texttt{-}\}$

$$
\begin{aligned}
\mathrm{x}^i &= \mathrm{x}_1 \wedge \neg\mathrm{x}_2 \wedge \neg\mathrm{x}_3 \wedge \mathrm{x}_4 \\
\mathrm{x}^j &= \mathrm{x}_1 \wedge \neg\mathrm{x}_2 \wedge \mathrm{x}_3 \wedge \neg\mathrm{x}_4 \\
\Delta\mathrm{x}^{ij} &= \mathrm{x}_1^{\texttt{=1}} \wedge \mathrm{x}_2^{\texttt{=0}} \wedge \mathrm{x}_3^{\texttt{+}} \wedge \mathrm{x}_4^{\texttt{-}}
\end{aligned}
$$

AKL with Boolean tuple representation of cases

Generalizable to attribute-value pairs

- For $\mathcal{D} = \{=1, =0, +, -\}$

$$
\begin{array}{rcccccccc}
\mathrm{x}^i & = & \mathrm{x}_1 & \wedge & \neg\mathrm{x}_2 & \wedge & \neg\mathrm{x}_3 & \wedge & \mathrm{x}_4 \\
\mathrm{x}^j & = & \mathrm{x}_1 & \wedge & \neg\mathrm{x}_2 & \wedge & \mathrm{x}_3 & \wedge & \neg\mathrm{x}_4 \\
\Delta\mathrm{x}^{ij} & = & \mathrm{x}_1^{=1} & \wedge & \mathrm{x}_2^{=0} & \wedge & \mathrm{x}_3^{+} & \wedge & \mathrm{x}_4^{-}
\end{array}
$$

  - Applying FCI extraction program gives birth to conjunctions such as $x_2^{+} \wedge x_3^{=0} \wedge y_1^{=1} \wedge y_2^{-}$ that can be interpreted as an adaptation rule.

AKL with Boolean tuple representation of cases

Generalizable to attribute-value pairs

- For $\mathcal{D} = \{\texttt{=1}, \texttt{=0}, \texttt{+}, \texttt{-}\}$

$$
\begin{array}{rcccccccc}
\mathtt{x}^i & = & \mathtt{x}_1 & \wedge & \neg\mathtt{x}_2 & \wedge & \neg\mathtt{x}_3 & \wedge & \mathtt{x}_4 \\
\mathtt{x}^j & = & \mathtt{x}_1 & \wedge & \neg\mathtt{x}_2 & \wedge & \mathtt{x}_3 & \wedge & \neg\mathtt{x}_4 \\
\Delta\mathtt{x}^{ij} & = & \mathtt{x}_1^{=1} & \wedge & \mathtt{x}_2^{=0} & \wedge & \mathtt{x}_3^{+} & \wedge & \mathtt{x}_4^{-}
\end{array}
$$

  - Applying FCI extraction program gives birth to conjunctions such as $x_2^{+} \wedge x_3^{=0} \wedge y_1^{=1} \wedge y_2^{-}$ that can be interpreted as an adaptation rule.

- For $\mathcal{D} = \{\texttt{=}, \texttt{+}, \texttt{-}\}$

$$
\begin{array}{rcccccccc}
\mathtt{x}^i & = & \mathtt{x}_1 & \wedge & \neg\mathtt{x}_2 & \wedge & \neg\mathtt{x}_3 & \wedge & \mathtt{x}_4 \\
\mathtt{x}^j & = & \mathtt{x}_1 & \wedge & \neg\mathtt{x}_2 & \wedge & \mathtt{x}_3 & \wedge & \neg\mathtt{x}_4 \\
\Delta\mathtt{x}^{ij} & = & \mathtt{x}_1^{=} & \wedge & \mathtt{x}_2^{=} & \wedge & \mathtt{x}_3^{+} & \wedge & \mathtt{x}_4^{-}
\end{array}
$$

AKL with Boolean tuple representation of cases

Generalizable to attribute-value pairs

- For $\mathcal{D} = \{\texttt{=1}, \texttt{=0}, \texttt{+}, \texttt{-}\}$

$$\begin{array}{lcccccccc} \mathtt{x}^i & = & \mathtt{x}_1 & \wedge & \neg\mathtt{x}_2 & \wedge & \neg\mathtt{x}_3 & \wedge & \mathtt{x}_4 \\ \mathtt{x}^j & = & \mathtt{x}_1 & \wedge & \neg\mathtt{x}_2 & \wedge & \mathtt{x}_3 & \wedge & \neg\mathtt{x}_4 \\ \Delta\mathtt{x}^{ij} & = & \mathtt{x}_1^{\texttt{=1}} & \wedge & \mathtt{x}_2^{\texttt{=0}} & \wedge & \mathtt{x}_3^{\texttt{+}} & \wedge & \mathtt{x}_4^{\texttt{-}} \end{array}$$

  - Applying FCI extraction program gives birth to conjunctions such as $x_2^{\texttt{+}} \wedge x_3^{\texttt{=0}} \wedge y_1^{\texttt{=1}} \wedge y_2^{\texttt{-}}$ that can be interpreted as an adaptation rule.

- For $\mathcal{D} = \{\texttt{=}, \texttt{+}, \texttt{-}\}$

$$\begin{array}{lcccccccc} \mathtt{x}^i & = & \mathtt{x}_1 & \wedge & \neg\mathtt{x}_2 & \wedge & \neg\mathtt{x}_3 & \wedge & \mathtt{x}_4 \\ \mathtt{x}^j & = & \mathtt{x}_1 & \wedge & \neg\mathtt{x}_2 & \wedge & \mathtt{x}_3 & \wedge & \neg\mathtt{x}_4 \\ \Delta\mathtt{x}^{ij} & = & \mathtt{x}_1^{\texttt{=}} & \wedge & \mathtt{x}_2^{\texttt{=}} & \wedge & \mathtt{x}_3^{\texttt{+}} & \wedge & \mathtt{x}_4^{\texttt{-}} \end{array}$$

  - *lazy AKL* with this $\mathcal{D}$ $\Longleftrightarrow$ *analogical extrapolation* on $\mathbb{B}^n$

AKL with Boolean tuple representation of cases

Generalizable to attribute-value pairs

- For $\mathcal{D} = \{\texttt{=1}, \texttt{=0}, \texttt{+}, \texttt{-}\}$

$$\begin{array}{ccccccccc} \mathtt{x}^i & = & \mathtt{x}_1 & \wedge & \neg\mathtt{x}_2 & \wedge & \neg\mathtt{x}_3 & \wedge & \mathtt{x}_4 \\ \mathtt{x}^j & = & \mathtt{x}_1 & \wedge & \neg\mathtt{x}_2 & \wedge & \mathtt{x}_3 & \wedge & \neg\mathtt{x}_4 \\ \Delta\mathtt{x}^{ij} & = & \mathtt{x}_1^{=1} & \wedge & \mathtt{x}_2^{=0} & \wedge & \mathtt{x}_3^{+} & \wedge & \mathtt{x}_4^{-} \end{array}$$

  - Applying FCI extraction program gives birth to conjunctions such as $x_2^{+} \wedge x_3^{=0} \wedge y_1^{=1} \wedge y_2^{-}$ that can be interpreted as an adaptation rule.

- For $\mathcal{D} = \{\texttt{=}, \texttt{+}, \texttt{-}\}$

$$\begin{array}{ccccccccc} \mathtt{x}^i & = & \mathtt{x}_1 & \wedge & \neg\mathtt{x}_2 & \wedge & \neg\mathtt{x}_3 & \wedge & \mathtt{x}_4 \\ \mathtt{x}^j & = & \mathtt{x}_1 & \wedge & \neg\mathtt{x}_2 & \wedge & \mathtt{x}_3 & \wedge & \neg\mathtt{x}_4 \\ \Delta\mathtt{x}^{ij} & = & \mathtt{x}_1^{=} & \wedge & \mathtt{x}_2^{=} & \wedge & \mathtt{x}_3^{+} & \wedge & \mathtt{x}_4^{-} \end{array}$$

  - *lazy AKL* with this $\mathcal{D} \iff$ *analogical extrapolation* on $\mathbb{B}^n$
  - Emmanuel Nauer, Jean Lieber, Mathieu d'Aquin, *Lazy Adaptation Knowledge Learning based on Frequent Closed Itemsets*, ICCBR-2023

Conclusion

Conclusion (sort of)

- Two fields of AI with
  - Differences of approaches, methods, vocabularies

Conclusion (sort of)

- Two fields of AI with
  - Differences of approaches, methods, vocabularies
  - Ideas to be shared...

Conclusion (sort of)

- Two fields of AI with
  - Differences of approaches, methods, vocabularies
  - Ideas to be shared...
  - Towards ICCBR
    = International Conference on analogy, i.e. Case-Based Reasoning?

Conclusion (sort of)

- Two fields of AI with
  - Differences of approaches, methods, vocabularies
  - Ideas to be shared...
  - Towards ICCBR
    = International Conference on analogy, i.e. Case-Based Reasoning?
- Use of analogical proportions for CBR
  - Difficulty: $a : b :: c : d$ in the same universe $\mathcal{U}$ whereas $\mathrm{x}^s, \mathrm{x}^{\mathtt{tgt}} \in \mathcal{P}$ and $\mathrm{y}^s, \mathrm{y}^{\mathtt{tgt}} \in \mathcal{S}$

Conclusion (sort of)

- Two fields of AI with
  - Differences of approaches, methods, vocabularies
  - Ideas to be shared...
  - Towards ICCBR
    = International Conference on analogy, i.e. Case-Based Reasoning?
- Use of analogical proportions for CBR
  - Difficulty: $a:b::c:d$ in the same universe $\mathcal{U}$ whereas $\mathrm{x}^s, \mathrm{x}^{\mathrm{tgt}} \in \mathcal{P}$ and $\mathrm{y}^s, \mathrm{y}^{\mathrm{tgt}} \in \mathcal{S}$
  - Taken into account:

Conclusion (sort of)

- Two fields of AI with
  - Differences of approaches, methods, vocabularies
  - Ideas to be shared...
  - Towards ICCBR
    = International Conference on analogy, i.e. Case-Based Reasoning?
- Use of analogical proportions for CBR
  - Difficulty: $a:b::c:d$ in the same universe $\mathcal{U}$ whereas $\mathrm{x}^s, \mathrm{x}^{\mathtt{tgt}} \in \mathcal{P}$ and $\mathrm{y}^s, \mathrm{y}^{\mathtt{tgt}} \in \mathcal{S}$
  - Taken into account:
    - When $\mathcal{P} = \mathcal{S}$

Conclusion (sort of)

- Two fields of AI with
  - Differences of approaches, methods, vocabularies
  - Ideas to be shared...
  - Towards ICCBR
    $=$ International Conference on analogy, i.e. Case-Based Reasoning?
- Use of analogical proportions for CBR
  - Difficulty: $a\!:\!b\!::\!c\!:\!d$ in the same universe $\mathcal{U}$ whereas $\mathrm{x}^s, \mathrm{x}^{\mathrm{tgt}} \in \mathcal{P}$ and $\mathrm{y}^s, \mathrm{y}^{\mathrm{tgt}} \in \mathcal{S}$
  - Taken into account:
    - When $\mathcal{P} = \mathcal{S}$
    - Or by analogical extrapolation

Future directions

- Considering this work with a query-result model of cases

Future directions

- Considering this work with a query-result model of cases
- How could adaptation knowledge be integrated in proportional analogies?

Future directions

- Considering this work with a query-result model of cases
- How could adaptation knowledge be integrated in proportional analogies?
- How could domain knowledge be integrated in proportional analogies?

A nice drawing to finish the talk