Analogy, and the like.

By Diarmuid O'Donoghue, Department of Computer Science, NUI Maynooth. 2000.
http://www.cs.may.ie/~dod

Metaphoric Language

George Lakoff

Is metaphor important?

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Metaphor is everywhere

- *Why are the following words used to describe Economic issues?*
  - *"Britain was deep in recession while Germany was flourishing three years ago. France kept moving ahead steadily long after Germany had fallen into recession. But now France is plunging deeper while the German economy continues to struggle. Britain has been taking small steps toward stimulating its economy by cutting interest rates, and has finally started to emerge from recession."*
- A race is seen as a metaphor for Economics
- Recession is a hole that is difficult to get out of

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Semantic Linguistics

- Deals with the "meaning" of language
  - not (really) concerned with earlier processing
  - semantics my occur in parallel with parsing
- Predicate calculus used as representation
  - `cause(hate(sam,cat), kill(sam,cat))`
- What do statements like these really mean?
  - Saddam is like Hitler
  - An atom is like the Universe
  - Time is (like) money

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A Central Cognitive Agency

- Analogical Reasoning plays a part in many Cognitive process
  learning, categorisation, induction, creativity
  Analogy is said to be a "Central Cognitive Process"

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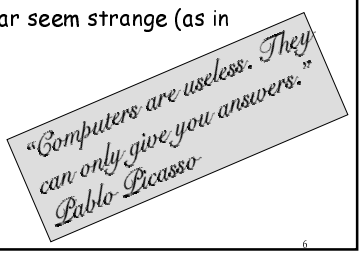
Analogical Reasoning

- Analogy uses similarity between a new domain and a well-known one to
  - make the strange seem familiar
  - make the familiar seem strange (as in creativity?)



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Different "viewpoints"

- How can all the following be true?
- What does each mean?

- Bill Gates is like Henry Ford
- Bill Gates is like Hitler

- Microsoft is like McDonalds
- Microsoft is like the Roman Empire

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Analogies structure our thoughts

- Analogical Reasoning operates at the **Cognitive** level
  - not neural, or social...

"We didn't have metaphors in our day, we didn't beat about the bush"
Anon.

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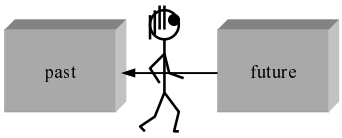
Basic Analogies

- Many cognitive perceptions are analogically structured using simple comparisons
  - Containership supports some basic metaphors
  - put the past *behind* us, look *forward* to the future, *in* the future, *back* then,



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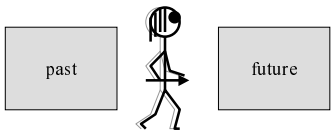
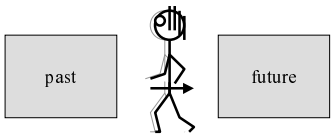
Basic Analogies





Yanomani indians

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Metaphors

- Sometimes we have no other way to talk about ideas
  - we treat a "black hole" as though its an object, rather than as an absence of objects from our universe...
- WWW is-like:
  - printing press, telephone network, broadcast, community bulletin board
- Novel ideas frequently are described by (novel) metaphors - and even arise from them...

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Problem Solving

- Most reasoning is Not performed "from first principles"
  - Derivational Analogies reuse past planning strategies to produce better results
- Many problems are solved by identifying similarity with past examples
  - Experientially based reasoning
  - Common law

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Analogies in Science

Biology
- The Heart is a Pump
- The eye is a camera
- The Brain is a telephone switchboard
- The Mind-Brain is a :
  - Symbolic Machine
  - Logic Machine
  - Neural Network

Physics
- Gas is like a container of billiard balls
- Sound moves like waves in water
- Light is like sound
- Electricity flow is like Water flow
- An Atom is like the Universe

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Black Holes emit matter

- Extremely dense collapsed star
  - interpreted by "Black Hole" analogy
- Initial records of black holes emitting radiation were dismissed
  - because of incompatibility with the "black hole" analogy
  - Note: Analogies can also "blind" us to reality

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Unbearable lightness of being

- Sometimes physicists thing of light as a wave, at other times a particle
  - Light :: particle
  - Light :: wave
  - but which is correct?
- The only *duality* in light exists in our minds
  - light is light - how *we* interpret light varies with context

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Simple Analogies

Lets look at some simple analogies in detail

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Letter String Analogies

- Consider the letter strings
  - abc:abd :: wxy: *wxz* successor of last
  - abc:abd :: wxy: *abd* replace r.h.s.
  - abc:abd :: xyz: *xya* successor of last ?
- Complex structures
  - abc:acdd :: wxy: *wyzz*
  - abc:ddab :: wxy: *zzwx*
  - abc:ddab :: wxy: *zzwx*
- see CopyCat by Hofstadter & Mitchell

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Numerical Analogies

- Digit sequences
  - 1:2 :: 3: *4*
  - 1:2 :: 3: *6*
  - 1,2,3:1,2,4 :: 567: *568*
- Number sequences
  - 2:4 :: 8: *10*
  - 2:4 :: 8: *16*
  - 123:124 :: 789: *7810*
- Functionally Derived
  - 2:4 :: 3: *27*

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Simple Analogies

- Partonomy
  - bird:wing :: person: *arm*
- Antonym Relationships
  - tall:short :: big: *small*
- Categorisation
  - tuna:fish :: dog: *animal*
- Domain dependency
  - fish:water :: bird: *air*
- Function
  - pen:write :: gun: *shoot*

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Analogies can be Ambiguous

- Which is correct ?
  - 2:4 :: 6: *8*
  - 2:4 :: 6: *12*
- Should we focus on digits or numbers ?
  - 123:124 :: 567: *568*
  - 123:124 :: 789: *7810*
- Problems are much greater with more ambiguous information

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Lexical Structure

- Syntactic categories
  - kick:verb :: kicker: *noun*
- Morphological "rules"
  - run:running :: write: *writing*
- Syntax learning
  - similarity of parse trees supports learning of word categories etc.

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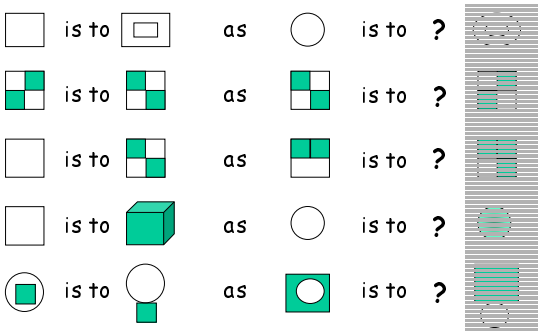
What's the answer?



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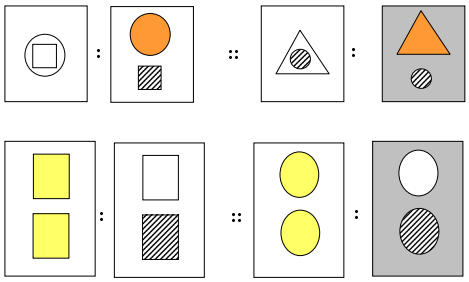
Local Attribute Matching



Objects and their attributes are "bound together", and treated as a unit (Bohan & O'Donoghue, 2000)

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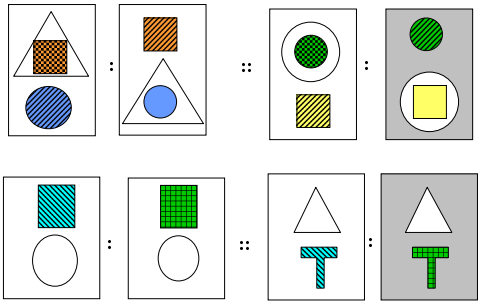
Local & Global Attribute Matching



These two problems are fundamentally different.

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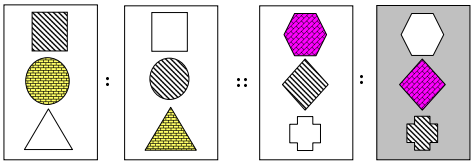
Global Attribute Matching



Here, we must treat the attributes separately from the objects (Bohan & O'Donoghue, 2000)

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Analogy is Asymmetric

- Analogies are directed (asymmetric) comparisons between concepts
  - "A man is like a pig"
    - and so is unclean and smelly
  - but "A pig is like a man"
    - and so is wise and intelligent

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Phases of Analogy

But what EXACTLY is an Analogy?

Analogy Definition

- Analogy is a structural comparison between conceptual domains of information, that supports learning.
  - Dedre Gentner, 1983
  - therefore object similarity is irrelevant, only predicates count!

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Predicate Representation

- **First-order** predicates specify relationships between objects
  - `collide(bus, car)`
- **Attributes** are 1-place predicates specifying qualities of objects
  - `red(car)`
- **High-order** predicates specify relationships between (first-order) predicates
  - `cause(collide, damage)`

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Systematicity

Dedre Gentner

- Systematicity = Identical Information Structures
- "Systematicity" implies the existence of two (near) identical Predicate structures
- **Metaphor** : Isomorphism already exists
- **Analogy** : Isomorphism must be enforced
  - by adding extra facts to the "target" domain

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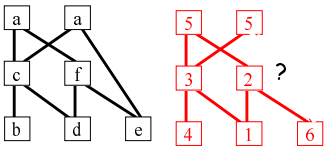
Structure gives the Mapping!

Source :
a (c , f)
f (d , e)
a (c , e)
c (d , b)

Target :
3 (1 , 4)
5 (3 , 2)
2 (1 , 6)
5 (3, 1 ?

So the required Mapping is:
a = 5
c = 3
f = 2
b = 4
d = 1
e = 6



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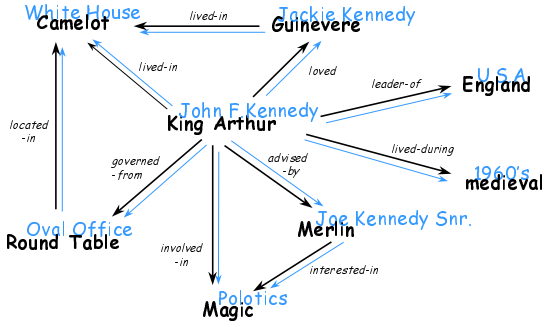
"JFKs White house is like Camelot"



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Camelot Analogy : Objects Only

- White House
- John F. Kennedy
- Jackie Kennedy
- Robert Kennedy
- Joe Kennedy Snr.
- Politics
- Oval office
- America
- Democratic nomination
- Camelot
- King Arthur
- Guinevere
- Sir Lancelot
- Merlin
- Magic
- Round table
- England
- Excalibur

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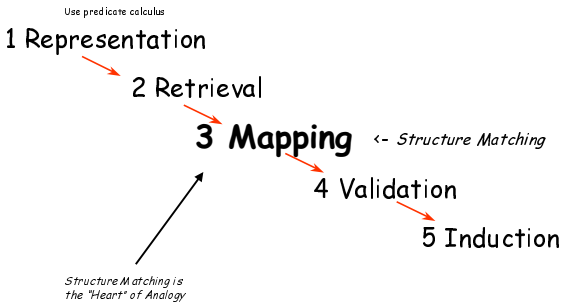
Other Analogical phases



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Mapping Models

Computational Models of the core Mapping phase

Models of the Mapping stage

- Given two sets of predicates (for source and target) we want to find the mapping between them
- Structure Mapping ε NP-Complete
- Computational Models Include:
  - **SME** (optimal), (also SME-heuristic)
  - **ACME** parallel neural network solution,
  - **IAM** incrementally based

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SME Structure Mapping Engine

- SME identifies mappings by first building small matches (MH) between individual predicates, and merging these into large global mappings (Gmaps).

1) MH - Match Hypothesis construction
   - between Source and Target predicates, and also both sets of objects
2) P-map construction finds MH's that are supportive of one another

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SME find "Best" Mapping

- 3) G-map Global map construction - merges Pmaps maximal sized, globally consistent sets of P-map combinations
- Essentially, the mapping chosen is the largest of all G-maps

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SME & DFS

- SME uses a depth first search process to combine individual MH's
- The deepest tree represents the largest structurally consistent mapping possible between Source and Target
  - SME is exhaustive and tries every possible combination of MH's

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Structure Mapping Engine

- SME problems
  - only the Mapping phase is addressed
  - Domains have pre-identified boundaries
  - cannot easily integrate into a larger cognitive framework
  - serious scaleability limitations

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ACME

- Identifies mapping using a parallel constraint satisfaction network
- Nodes are generated to represent all possible s:t pair mappings
- 2 types of bi-directional Links inserted between these nodes ($w_{ij} = w_{ji}$)
  - **positive** connections between supporting hypotheses
  - **negative** connections between alternative mappings for individual predicates/objects

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ACME

- Each node starts off with a small positive output value.
- A formula governs how to update the value of each node
  - positive inputs are treated separately for negative ones

$$Out_{t+1}^{i} = Out_{t}^{i} + \alpha \sum_{j\,positive-inputs} w_{ij} Out_{t}^{j} + \beta \sum_{j\,negative-inputs} w_{ij}\ Out_{t}^{j}$$

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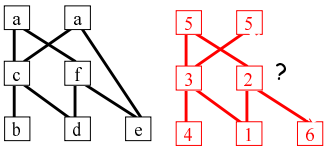

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ACME - Generate Nodes

Source :
a (c , f)
f (d , e)
a (c , e)
c (d , b)

Target :
3 (1 , 4)
5 (3 , 2)
2 (1 , 6)
5 (3, ?)

A=3 A=5 A=2

F=3 F=5 F=2 F=4

etc…

c=1 c=3

etc…

Nodes have labels attached telling what partial mapping they represent (a=>5)

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Add Negative links

- Only one matching for every node is allowed!
- So, negative connections are inserted between nodes with "competing" labels!

A=3 A=5 A=2

F=3 F=5 F=2

c=1 c=3

Competitive links are set to -1

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Add Positive Links

Source :
~~a (c , f)~~
f (d , e)
a (c , e)
c (d , b)

Target :
~~3 (1 , 4)~~
~~5 (3 , 2)~~
2 (1 , 6)
5 (3, ?)

Aha, so if a=3, then c must be assigned to1. This corresponds to a Positive connection between these nodes

A=3 A=5 A=2

F=3 F=5 F=2 F=4

c=1 c=3

Positive connections, set to +1.

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ACME eg

Continue adding links between nodes that support each other, using the structure of the problem data.

A=3 A=5 A=2

F=3 F=5 F=2 F=4

c=1 c=3

if a=5, then c must be assigned to 3 AND f assigned to 2
…plus Many more links

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ACME eg

- The largest block of "positively" connected neurons will "collect" all the "energy" in the system".
  - The labels of all active nodes represent the analogical mapping!

A=3 A=5 A=2

F=3 F=5 F=2 F=4

c=1 c=3

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IAC & Hopfield

- ACME's equation causes "energy" to collect in large interconnected systems of nodes.
  - It uses an "un proven" neural network called IAC
- ACME could also have used a Hopfield network
  - a global energy equation would ensure that all energy Always collected in such nodes.

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IAM

- Incremental Analogy Machine
- Find-**Roots**: First finds deeply nested trees of predicates in each domain
- Root-mapping: map each predicate tree, dependent upon size, etc.
  - thereby reducing the number of predicate mappings that must be considered.
- Root-merge: merge root tree mappings into larger consistent groupings

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IAM

- Incremental Analogy Machine
- Finds Trees of predicates in both domains
- Matches large tress together, building up a mapping bit-by-bit

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Analogical Inference

How do Analogies cause Inference?

Analogical Inference

$B, T \subset Th$;	Base and Target Theories
P_b, Q_b	$P_b, Q_b \in B$
$P_b \rightarrow Q_b$	Q_b is-like P_b
P_t	$P_t \in Th$
$P_b \sim= P_t$	P_b is similar to P_t
Q_t	

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Simple Proportional Analogies

- a:b :: c:d read a is-to b as c is-to d
  - d unknown

1 <a r1 b>
  r1 relates A and B (successor)

2 Assume equality between r1 and r2
  <r1 R3 r2> R3 is "equals"

3 <c r2 d>
  r2 allows d to be computed

$\therefore$ c r2 d

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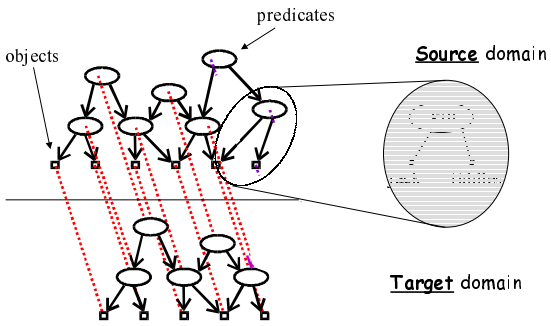
Data representation



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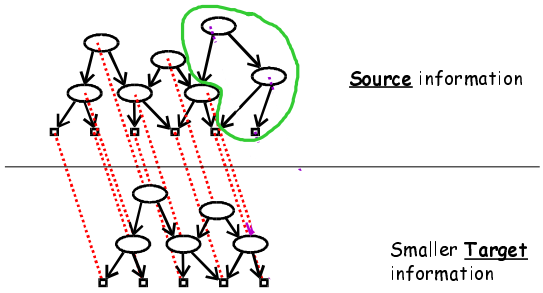
Before making the analogy

- First find out what two things have in "common"



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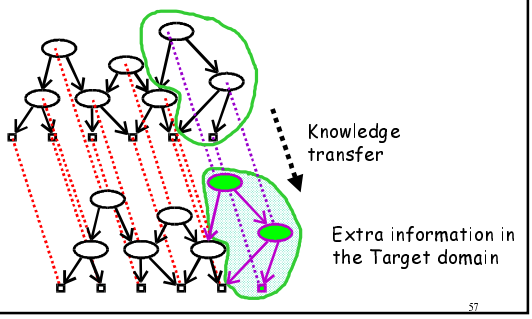
Learning from the Analogy

- Then, use this similarity to support Learning!



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