The Interaction of Representation and Reasoning

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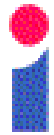
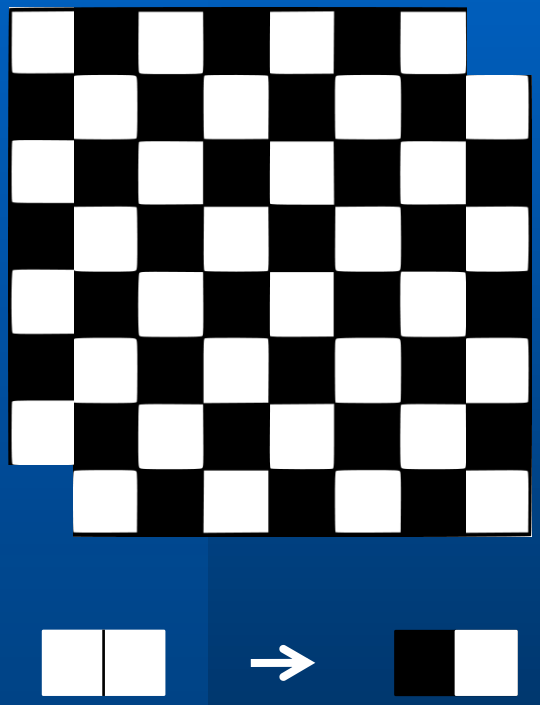


Agents must have World Models

- **Internal model needed:**
  - **to predict the effects of actions during planning.**
  - **Including models of other agents.**
  - **Called *ontologies*.**
- **World infinitely rich.**
  - **Any model is an approximation.**
  - **Must find sweet spot, trading expressivity against efficiency.**
- **Each agent will have an ontology tuned to its role.**
  - **Appropriate representation is key to effective problem solving, e.g., reduce search.**
- **However, agents must communicate.**
  - **So ontologies must be aligned.**

Representation as the Key 1

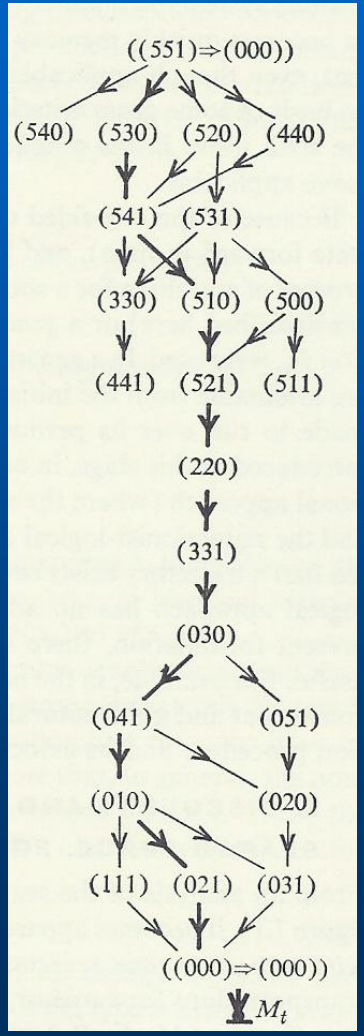


John McCarthy's
Mutilated Checkerboard:
Can we tile board with dominos?

Colouring of domino removes search from solution.

Representation as the Key 2

- **Saul Amarel study of missionaries and cannibals.**
- **How change of representation affects search space size.**
- **Successive representations significantly reduce search.**



Representation as the Key 3

Andy deSessa's

Bouncing Ball: Where does energy go at moment of impact?

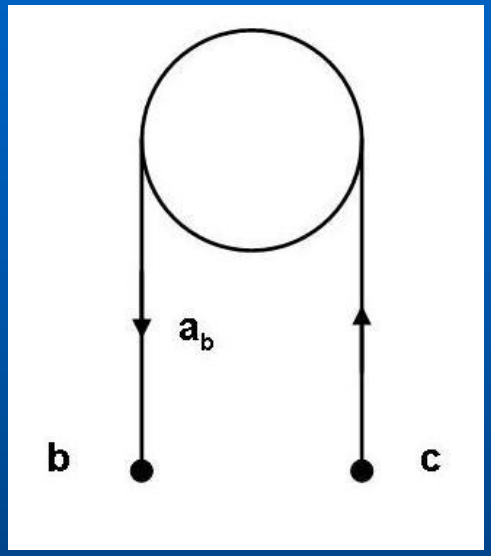
Essential to idealize ball as having extent.

Automated Representation Formation

- **Representation must be tuned to goal and environment.**
- **Design representation to suit problem.**
- **Abstract relevant information from sensory input: idealization.**
- **Decide what is negligible and can be ignored.**

Formation of Representations 1

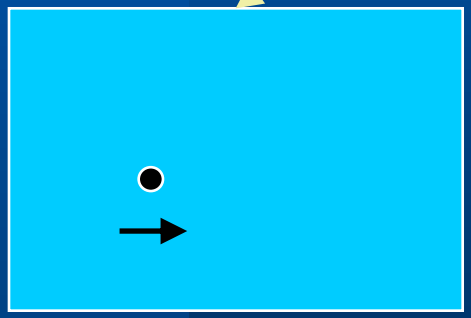
- **Mecho Project: solve mechanics problems stated in English.**
  - **Project with George Luger, Martha Palmer, Bob Welham, Chris Mellish, Rob Milne.**
- **Real world objects idealized automatically.**
  - **particles, inextensible strings, light pulleys.**
- **Idealization fossilized:**
  - **inferred from problem type.**



Idealisation

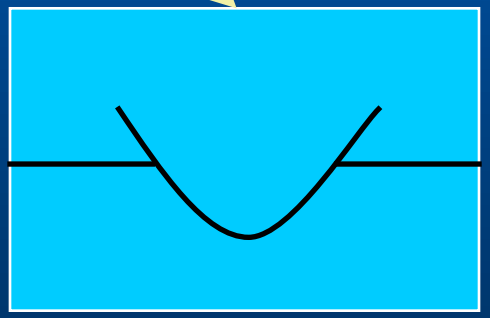
How to idealise this ship?

Relative Velocity Problem



Particle on plane

Archimedes Principle Problem



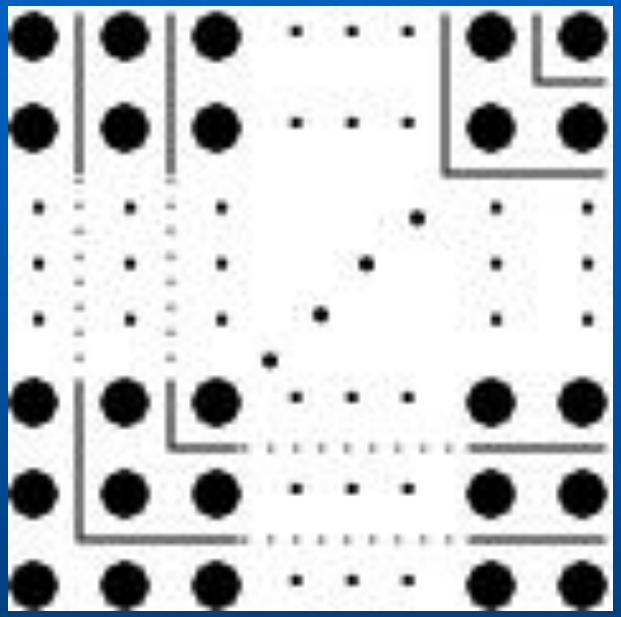
Container in fluid

Formation of Representations 2

- **Eco project: assist users to construct ecological model.**
  - **Project with Bob Muetzelfeldt, Mike Uschold, Dave Robertson.**
- **Heuristics for suggesting idealizations.**
- **Representation formation as interaction between human and machine.**

Formation of Representations 3

- **Diamond Project: constructs 'proofs without words'.**
  - **PhD project of Mateja Jamnik.**
- **n^2 idealized as both**
  - ***n* rows of n dots**
  - ***n* ell shapes**
- **Idealizations chosen via human interaction.**



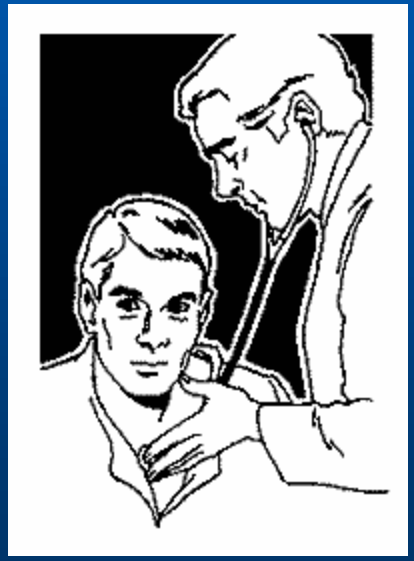
$$n^2=1+3+\ldots+2n-1$$

Ontologies must Evolve.

- **Ontologies must evolve:**
  - **as world changes;**
  - **as problems change;**
  - **to communicate with other agents.**
- **Most ontologies built by designer and static.**
- **Ontology evolution must be dynamic and automated:**
  - **Consider emergency response;**
  - **Multiple agencies – must inter-operate.**

Repairing Faulty Representations

- **Representation is a fluent!**
  - **Need to react to changing world,**
  - **and changing goals,**
  - **and other agents' ontologies,**
  - **and inconsistencies.**
- **Faulty representation can be signalled by inference failure.**
- **Need to diagnose and repair.**
  - **Both beliefs and language.**



Triggers for Representational Change

- **Can prove false conjectures.**
- **Fail to prove true conjectures.**
- **Reasoning inefficient.**

Analysis of failure can suggest appropriate repair.

Ontology Evolution 1: Coin-in-the-slot

- **Parking meter requires £5.**

- **Must be in coins.**

- **Not including new 50p.**

- **Or bent or underweight coins.**

- **But some foreign coins will work.**

Ontology Evolution 2: Motherhood

- **Motherhood: Mother(person)**
  - **MaternalGrandMother(p) = Mother(Mother(p))**
- **Types: natural, step, adopted, foster, surrogate, egg donor, ...**
  - **Mother must be predicate, not function.**
- **Split Relations: StepMother(mum,child)**
- **Add Argument: Mother(mum,child,kind)**
  - **Mother(gm,m,k_1) & Mother(m,gc,k_2) → MaternalGrandMother(gm,gc,Combine(k_1,k_2))**

Ontology Evolution 3: Latent Heat

- **Latent heat: change of heat content without change of temperature.**
  - **Black discovered in 1761.**
- **Before Black, heat and temperature conflated.**
- **Separation of conflated concepts necessary precursor to discovery.**
- **Conflation of “morning star” and “evening star” into “Venus” in reverse direction.**

Representation Evolution in Programs

- **Cynthia: analogical editor for ML programs.**
  - **Edit old ML program into new one.**
  - **PhD project of Jon Whittle.**
- **Powerful commands to change names, arguments, types, recursion, etc.**
- **Commands edit synthesis proof, from which program is rederived.**
  - **Ensures well-formedness, coverage and termination of synthesised program.**

length([])=0

length([H|T])=length(T)+1

Example: Length to Size

- **Initial Program: length of list.**
- **Change to count size of tree.**
- **Change data-type to trees.**
  - **Automatically changes recursion.**
  - **Flags up now faulty code.**
- **Correct flagged code.**
  - **Checks termination.**
- **Change name of program to count**

count(leaf(S))=1

count(node(L,R))=count(L)+count(R)

Representation Evolution for Agents

- **ORS: repairs faulty ontologies by analysing failed multi-agent plans.**
  - **PhD project of Fiona McNeill.**
- **Changes include abstraction and refinement of language,**
  - **e.g., adding arguments, changing predicates.**
- **Allows agents with slightly different ontologies to communicate.**
- **Technology essential for Semantic Web**

Example: Hotel Bill

- **Planning agent (*PA*) forms plan,**
  - **but it fails.**
- **Failing action: *Pay(PA, Hotel, £200).***
  - **Hotel agent refuses to accept money.**
- **Surprising question precedes failure.**
  - ***Money(PA, £200, Credit_Card)***
  - **Where *PA* expected *Money(PA, £200)***
- **Change binary *Money* to ternary.**

Representation Evolution in Physics

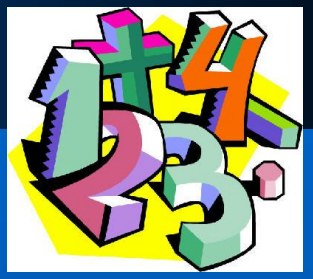
- **GALILEO: evolves physical theories.**
  - **Project with Michael Chan & Jos Lehmann.**
- **Experimental evidence may contradict known theory.**
- **Using *ontology repair plans* to capture common patterns.**
  - **Where's my stuff?**
  - **Inconstancy.**
  - **Unite.**
- **Case studies include: dark matter, latent heat, Boyle's Law, etc.**

Example: Dark Matter

- **Mismatch between prediction and observation:**
  - **orbital velocities of stars in spiral galaxies.**
- **Split galaxy into:**
  - **visible stars;**
  - **invisible dark matter;**
  - **and their total.**

- **Alternative solution via MOND:**
  - **gravity depends on relative acceleration.**

Representation Evolution in Maths



- **HR Program creates new concepts and conjectures from examples.**
  - **PhD project of Simon Colton.**
- **TM Program uses HR, Otter and Mace to repair faulty mathematical ontologies.**
  - **PhD project of Alison Pease.**
- **TM methods based on Lakatos "Proofs and Refutations".**

Example: Faulty Conjecture

- **TPTP: non-theorem in Ring Theory.**
  - $\forall x,y.\ x^2 \times y \times x^2 = e.$
- **Mace: finds 7 examples and 6 counter-examples.**
- **HR: invents new concept: $\forall z.\ z^2=z+z$.**
- **TM: applies Lakatos's *Strategic Withdrawal.***
- **Otter: proves conjecture for all rings with above property.**

Conclusion

- **Formation of representation must be under machine control.**
  - **To deal with multiple agents, changing world.**
- **Representational change triggered, for instance, by reasoning failures.**
  - **Language changes as well as belief revision.**
- **Major challenge for next half century.**