Intelligence, commonsense, and cognitive development

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1. a vascular ductless organ in the left upper abdomen of humans and other vertebrates that helps to destroy old red blood cells, form lymphocytes, and store blood
Alan Turing
Underestimating the challenge of common sense intelligence

- Turing test
Underestimating the challenge of common sense intelligence

“I believe that in about fifty years' time it will be possible to program computers ... to make them play the ... game so well that an average interrogator will not have more than 70 percent chance of making the right identification after five minutes of questioning” (Turing, 1950)
Is this a good test of intelligence?

- Searle’s Chinese room … maybe not.
Underestimating the challenge of common sense intelligence

RECENT WINNERS OF THE LOEBNER PRIZE

Can you read?
Yes -- what’s your favorite novel?
There’s no such thing.
Meaning you don’t have a favorite novel or novels don’t exist?
No
What’s your favorite book then?
Are you serious? I don’t have a favorite book. My favorite color is transparent.
Underestimating the challenge of common sense intelligence

RECENT WINNERS OF THE LOEBNER PRIZE

Do you have a pet?
No but I like cats very much.
Why don’t you have a cat?
Do I need one?
Only if you think you do.
I think I do.
Well then get one by God!
Good reasoning! Where can I get one by God?
Commonsense as the hard problem of cognitive science

Suppose you wanted to engineer commonsense how would you do it?

Douglas Lenat: maybe the trick is just to give computers a bunch of facts about the world

- But if knowledge is organized as individual facts, you would have to know that if Barack Obama is in Washington, so is his eyebrow, his big toe, his spleen …

- Hubert Dreyfus: “If you got all that knowledge into a computer you would not know how to retrieve it.”
Or not ... 

- **Watson (16:48-16:50)**
- So Dreyfus’ problem turns out not to be the problem
- The hard problem may be that even having massive world knowledge is neither necessary nor sufficient for passing the Turing test.
- “Hedgehogs are covered with quills or spines which are hollow hairs made stiff by this protein ...”
- Keratin = 99%, Porcupine = 36%
Common sense as the hard problem of cognitive science

• “Is it easier to walk forwards or backwards?”
• “If President Obama is in Washington, is his spleen in Washington?”
• “Do doctors wear pants?”

Everything you needed to know to pass the Turing test you learned before kindergarten.
Most of the hard problems of cognitive science …

- natural language understanding
- scene understanding
- face recognition
- motor planning
- causal reasoning
- theory of mind
- moral reasoning
- Are readily solved by young children.
We would like to know

- What causes this knowledge to emerge.
- How the knowledge is represented.
- Whether this knowledge changes and if so why.
- How knowledge in one area interacts with knowledge in other areas.
- Not just a hard problem of cognitive science but an old problem of philosophy …
Background

- From the beginning of Western philosophy: two competing traditions.
- **Rationalism** -- Knowledge of that which is necessarily true is innate. (Plato)
- **Empiricism** -- "Nothing is in the intellect which was not first in the senses." (Aristotle)
- But the puzzle of common sense is how we can be so confident about knowledge that is neither
  - innate (e.g., about spleens)
  - nor necessarily true (you can actually live without a spleen -- although I don’t recommend it)
- Bothered a lot of philosophers (Kant: “How are synthetic a priori truths possible?”)
- Today -- how is inductive inference possible?
Common sense intelligence

• We need to explain the gap between experience and our understanding of it
• By now you may have already forgotten again why this is a hard problem ...
What gap? Try this multiple choice quiz

- A speaker of Quinian points to this and says “Gavagi.” What does Gavagai mean?
What gap? Try this multiple choice quiz

• Complete the sentence: “The giraffe has a very long ...”
What gap? Try this multiple choice quiz

• What’s behind the rectangle?
The problem of common sense intelligence

• Most of what we know is massively underconstrained by the data.

• Inductive inference as a chicken and egg problem ...

• we need abstract knowledge to constrain our interpretation of evidence

• but how do we get that abstract knowledge in the first place?
Core knowledge
Infancy revolution

Our results show that infants show surprise at this event only when the screen is too narrow to allow the ball and the box to both stand side by side behind the screen. When the screen is fairly large, infants, like adults, immediately conclude upon seeing the box, that the ball stopped behind the screen. By 7 months of age, infants are thus able to use the width of two objects to determine whether they can simultaneously hide behind the screen.

What should they do when hit?

Collision events

Our experiments on infants' reasoning about collision events have focused on simple problems involving a moving object (a cylinder that rolls down a ramp) and a stationary object (a large wheeled toy bug resting on a track at the bottom of the ramp). Adults typically expect the bug to roll down the track when hit by the cylinder. When asked how far the bug will be displaced, adults are generally reluctant to hazard a guess (they are aware that the length of the bug's trajectory depends on a host of factors about which they have no information). After observing that the bug rolls to the middle of the track when hit by a medium-size cylinder, however, adults readily predict that the bug will roll farther with a larger and less far with a smaller cylinder made of identical material.

Our experiments indicate that, by 2.5 months of age, infants already possess clear expectations that the bug should be displaced when hit by the cylinder (see Figure 3A), and should remain stationary when not hit (e.g., when a barrier prevents the cylinder from contacting the bug; see Figure 3B). However, it is not until 5.5 to 6.5 months of age that infants are able to judge, after seeing that the medium cylinder causes the bug to roll to the middle of the track, that the bug should roll farther with the larger but not the smaller cylinder (see Figure 3C). Younger infants are not surprised to see the bug roll to the end of the track with either the larger or the smaller cylinder, even though (a) all three of the cylinders are simultaneously present in the apparatus, so that their sizes can be readily compared, and (b) the infants have no difficulty remembering that the bug rolled to the middle of the track with the medium cylinder. These results suggest that, prior to 5.5 to 6.5 months of age, infants are unaware that the size of the cylinder can be used to reason about the length of the bug's trajectory.

Further results:

As was described above, it is not until 5.5 to 6.5 months of age that infants realize that the size of the cylinder affects the length of the bug's trajectory. One unexpected aspect of our results with this age group was that the infants were able to reason about the sizes of the cylinders only when all three were laid out side by side at the start of each event, making it possible for the infants to compare the cylinders' sizes in a single glance. The infants failed the task when they were shown only one cylinder at a time and hence had to rely on their memory of the medium cylinder to determine whether the cylinder before them was smaller or larger than previously. By 7.5 months of age, however, infants no longer had difficulty remembering the size of the medium cylinder and correctly predicted how far the bug should roll with the small and the large cylinders regardless of whether the cylinders were laid out side by side.
But abstract constraints don’t necessarily have to be innate

The blessing of abstraction suggests that this is not a necessary order for the construction of knowledge, but that abstract knowledge can become available before specific knowledge in any of the systems that it depends on.

Noah D. Goodman, Tomer D. Ullman, Joshua B. Tenenbaum
Induction, Overhypothesis, and the Origin of Abstract Knowledge: Evidence from 9-month-old Infants
Kathryn M. Dewar & Fei Xu

1. 

2. 

3. 

4. ??
Child as scientist
How do scientists learn?

- Scientists learn from statistical evidence
- Scientists’ beliefs affect their interpretation of statistical evidence
- Scientists distinguish genuine causes from spurious associations
- Scientists selectively explore ambiguous or confounded evidence
- Scientists introduce unobserved variables to explain data otherwise anomalous with respect to their prior beliefs
- Scientists’ generalizations depend on how evidence is sampled
- Scientists infer the relative probability of competing hypotheses and choose interventions most likely to achieve desired outcomes
- Scientists isolate variables to distinguish competing hypotheses
- Scientists rely on expert knowledge and trade-off instruction and exploration
Rational inference in early childhood

- Children learn from statistical evidence
- Children’s beliefs affect their interpretation of statistical evidence
- Children distinguish genuine causes from spurious associations
- Children selectively explore ambiguous or confounded evidence
- Children introduce unobserved variables to explain data otherwise anomalous with respect to their prior beliefs
- Children’s generalizations depend on how evidence is sampled
- Children infer the relative probability of competing hypotheses and choose interventions most likely to change target outcomes
- Children isolate variables to distinguish competing hypotheses
- Children rely on expert knowledge and trade-off instruction and exploration
It’s not that children are little scientists ...
It’s that science is possible because of the type of learning that is necessary in early childhood ...
Rational inference in early childhood

- Children learn from statistical evidence
- Children’s beliefs affect their interpretation of statistical evidence
- Children distinguish genuine causes from spurious associations
- Children selectively explore ambiguous or confounded evidence
- Children introduce unobserved variables to explain data otherwise anomalous with respect to their prior beliefs
- Children’s generalizations depend on how evidence is sampled
- Children infer the relative probability of hypotheses and choose interventions most likely to achieve desired outcomes
- Children isolate variables to distinguish competing hypotheses
- Children rely on expert knowledge and trade-off instruction and exploration
Four quick examples

- Infants’ generalizations depend on how evidence is sampled.
- Infants infer the relative probability of hypotheses and choose interventions most likely to achieve desired outcomes.
- Preschoolers’ isolate variables to distinguish competing hypotheses.
- Preschoolers rely on expert knowledge and trade-off instruction and exploration.
Four quick examples

• Infants’ generalizations depend on how evidence is sampled
  • Infants infer the relative probability of hypotheses and choose interventions most likely to achieve desired outcomes.

• Preschoolers’ isolate variables to distinguish competing hypotheses
  • Preschoolers rely on expert knowledge and trade-off instruction and exploration.
Child as scientist?

• Science requires generalizing properties from a small sample to a population.

• Can use category membership and feature similarity to infer that things that look alike will share properties.

• If you know that this sample of Martian rocks has a high concentration of silica, can infer that other Martian rocks may have a high concentration of silica.

• If you know that this sample of needles from a Pacific silver fir lie flat, can infer other Pacific silver fir needles lie flat.
Child as scientist?

• But as scientists we may know something about the sampling process that affects our inferences.

• Do all Martian rocks have high concentrations or silica or only dusty rocks on the surface?

• Do all Pacific silver fir needles lie flat or just those low on the canopy?

• How far we extend our generalizations depends on whether we think the sampling process was random or selective.

• Do infants’ generalizations also take the sampling process into account?
Consistent with sampling from whole box

Unlikely to have been sampled from whole box

More likely that evidence was sampled selectively

Prediction: Many children try to squeak and squeak persistently

Prediction: Few children try to squeak and children do not squeak often

The yellow ball probably doesn't squeak
Consistent with sampling from whole box
Unlikely to have been sampled from whole box
More likely that evidence was sampled selectively

Looks a lot like the other balls -- should try squeaking it
The yellow ball probably doesn't squeak

Prediction: Many children try to squeak and squeak persistently
Prediction: Few children try to squeak and children do not squeak often
**Result**

**Condition A**

**Condition B**

Toddlers: 13 -18 months; mean 15 months

**Mean Number of Squeezes**

- Condition A: 2
- Condition B: 1

**Number of Children**

- Condition A: 1.00
- Condition B: 0.50

![Gweon, Tenenbaum, & Schulz, PNAS, 2010](image-url)
What if…

• Shake the box upside down
  – And three blue balls fall out?

• Specifies that the balls had to be randomly sampled from the whole box.
  – Even though the sample is improbable, should generalize to whole box
The inference problem

- Sampling process & Property extension
Model assuming weak sampling (agents choose at random from the whole population)

Gweon, Tenenbaum, & Schulz, PNAS, 2010
Model assuming strong sampling (agents sample items selectively depending on the properties they have)
Model assuming joint inference

\[ \alpha = 0.5 \]

\[ \alpha = 0 \quad \alpha = 1 \]

- Blue 3balls
- Yellow 3balls
- Yellow 1ball
- Yellow 1ball Extended
- Yellow 3balls (rep)

Exp. 1

- Blue 3balls
- Yellow 3balls
- Yellow 1ball
- Yellow 1ball Extended
- Yellow 3balls (rep)

Exp. 2

Exp. 3

Exp. 4

Exp. 5

Gweon, Tenenbaum, & Schulz, PNAS, 2010
Child as scientist?

• 15-month-olds attend to more than the perceptual similarity of objects.

• Infants make graded inferences that are sensitive to both the amount of evidence they observe and the process by which the evidence is sampled.
Today’s talk

- Infants’ generalizations depend on how evidence is sampled
- Infants infer the relative probability of hypotheses and choose interventions most likely to achieve desired outcomes.
- Preschoolers’ isolate variables to distinguish competing hypotheses
- Preschoolers rely on expert knowledge and trade-off instruction and exploration
Fundamental problem of confounding: us and the world
Fundamental problem of confounding: us and the world

When you fail to achieve an expected outcome, did you do something wrong or is something wrong in the world?

Gweon & Schulz, 2011, Science
Results

N = 36 infants, mean: 16 months; range: 13-20 months

Gweon & Schulz, 2011, Science
Rational causal inference in infants

• 16-month-olds...
  – track the statistical dependence between agents, objects, and outcomes
  – can use minimal data to make rational attributions about the cause of failed goal-directed actions

• These distinct explanatory attributions (self vs. world) help them choose between two different strategies for learning
  • seeking instruction from others
  • self-guided exploration
Four quick examples

• Infants’ generalizations depend on how evidence is sampled
• Infants infer the relative probability of hypotheses and choose interventions most likely to achieve desired outcomes.
• **Preschoolers’ isolate variables to distinguish competing hypotheses**
• Preschoolers rely on expert knowledge and trade-off instruction and exploration
Children selectively engage in exploratory play when evidence fails to distinguish competing hypotheses (e.g., when evidence is confounded)
Unconfounded evidence
Confounded evidence
n = 16/condition
four & five-year-olds
mean: 57 months

Schulz & Bonawitz, 2007, Developmental Psychology
Children assigned to one of two training conditions

- all beads condition
- some beads condition
All children given the same test condition

stuck pair

separable pair

Cook, Goodman, & Schulz (in press) Cognition
n = 20/condition, mean: 54 months; range: 46-64 months

Cook, Goodman, & Schulz (in press) Cognition
Children assigned to one of two training conditions

all beads condition

some beads condition

Cook, Goodman, & Schulz (in press) Cognition
All children given the same test condition

stuck pair
All children given the same test condition

some beads condition

stuck pair

Cook, Goodman, & Schulz (in press) Cognition
All children given the same test condition

Cook, Goodman, & Schulz (in press) Cognition
Conclusions

• Preschoolers can use information about the base rate of candidate causes to distinguish the relative ambiguity of evidence.

• Given ambiguous evidence, children select -- and design -- potentially informative interventions that isolate relevant causal variables.
Four quick examples

• Infants’ generalizations depend on how evidence is sampled.

• Infants infer the relative probability of hypotheses and choose interventions most likely to achieve desired outcomes.

• Preschoolers’ isolate variables to distinguish competing hypotheses.

• Preschoolers rely on expert knowledge and trade-off instruction and exploration.
Assumptions about teaching

- Learner will rationally update her beliefs from evidence.
- The probability that a teacher will demonstrate some set of evidence is proportional to the probability that the learner will infer the target hypothesis given that evidence.
Assumptions about teaching

• If you assume that an adult is helpful and knowledgeable …
  – Can assume that evidence they show you is not only true
  – But helps distinguish the target hypothesis from other hypotheses.
Assumptions about pedagogy

• Thus for instance, if a knowledgeable teacher shows you \( n \) properties of a toy, should assume that there are not \( n + 1 \).

• If the same evidence is demonstrated by a naïve learner (or discovered by the child herself), should be much less likely to make this assumption (could well be more than \( n \)).

• Pedagogy strengthens the inference that absence of evidence is evidence of absence.
Predicts a trade-off between instruction and exploration

- If a knowledgeable teacher demonstrates properties of a toy, children should not engage in additional exploration.
- If a naïve learner demonstrates the same properties, children should make no such assumption and should explore broadly.
- Four interesting properties

PEDAGOGICAL
“Watch this, I’m going to show you my toy.”
[intentionally pull tube]
“Wow, see that?”

ACCIDENTAL
“Look at this neat toy I found here.”
[accidentally pull tube]
“Wow, see that?”

NO DEMO
“Look at this neat toy that I have.”
[rotate toy for child]
“Wow, see that?”

INTERRUPTED
Identical to Pedagogical except interrupted immediately after
“Wow, see that?”

- squeaker
- mirror
- light
- music
Pedagogical Condition
Rational (but challenging) trade-offs between instruction and exploration

The principal goal of education is to create men who are capable of doing new things, not simply of repeating what other generations have done - men who are creative, inventive and discoverers.

Jean Piaget.
Four quick examples

• Infants’ generalizations depend on how evidence is sampled
• Infants infer the relative probability of hypotheses and choose interventions most likely to achieve desired outcomes.
• Preschoolers’ isolate variables to distinguish competing hypotheses
• Preschoolers rely on expert knowledge and trade-off instruction and exploration
Back to intelligence ...

• Big mysteries remain ... in particular, how do learners generate new hypotheses? Where do new ideas come from?

  • How do we know when we are on the right track?

  • How do we distinguish “good” wrong ideas from “bad” ones?

  • How do we sometimes know we’ve arrived at the solution to a problem even before we have access to new evidence?
“There is something fascinating about science, one gets such wholesale returns of conjecture out of such a trifling investment in fact” (Mark Twain, 1883)
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