Children's Causal Learning

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Reviews

Gopnik,Glymour,Sobel,Schulz,Kushnir,& Danks, Psychological Review, 2004.
Gopnik & Schulz, Trends in Cognitive Science, 2004
Gopnik & Schulz (2007). Causal learning: psychology, philosophy, computation. Oxford University Press
Developmental Science Special Section on Bayes net and Bayesian learning (2007)

Why study children?

- Adults have extensive causal knowledge and often tuition in causal inference.
- Adults are less concerned with learning than with inference.
- The theory theory (Gopnik & Meltzoff 1997). Children are the best causal learners in the world, developing intuitive theories of psychology, biology and physics.

Contributions of Causal Graphical Models

- Allows learning of a range of coherent causal structure
- Integrates and distinguishes interventions and observations
- Allows for probabilistic learning
- Allows both overthrow and integration of prior knowledge

Learning in Animals

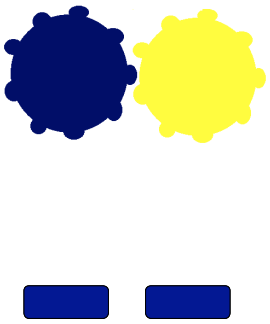
- Classical conditioning - Prediction of dependent probabilities
- Operant conditioning - Direct learning from own interventions
- Learning by imitation - Direct learning from other's interventions ? 9 months in children.
- Causal learning - Inferring interventions from observation and vice-versa ??? 24 months in children.

Criteria for Causal Learning

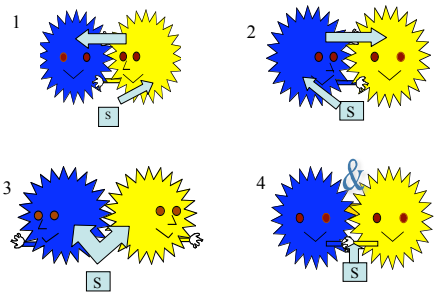
- Explicit causal judgments and explanations.
- Novel interventions.

Study 1.Inferring complex causal structure: Chains versus common effects versus conjunctions

- Schulz, Gopnik & Glymour, Developmental Science, 2007.
- Can young children use patterns of intervention and dependence to infer complex causal structures?

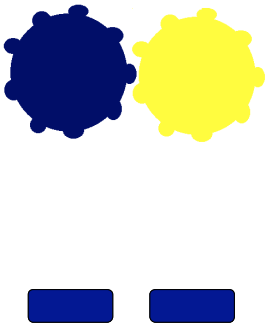


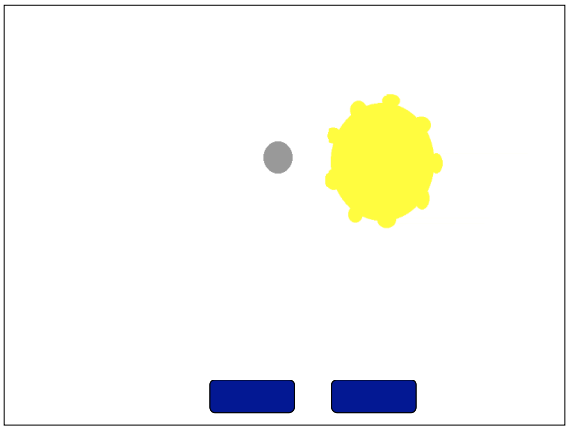
The Causal Possibilities

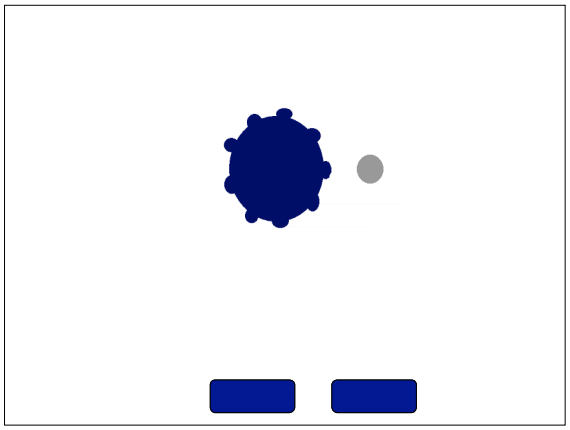


The Causal Mystery

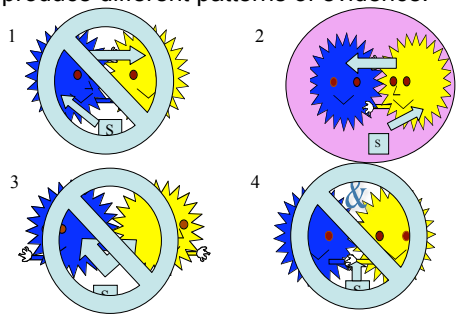
- These causal structures cannot be distinguished by:
  - Spatiotemporal cues
  - Associative strength
  - Direct interventions
  - Causal mechanisms
- In the world at large, cues to causal structure might be either redundant or absent.





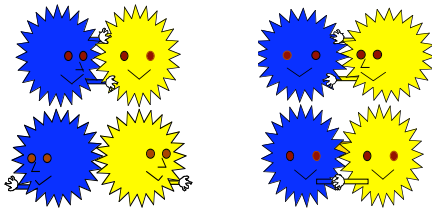


Interventions on each causal structure will produce different patterns of evidence.



Conditional interventions . . .

Knowing each gears' relationship to the switch let you determine the gears' relationship to one another . . .



Question

- Do formal assumptions about how patterns of conditional dependence and independence indicate causal relations, allow children to distinguish causes from effects and learn the structure of causal events?

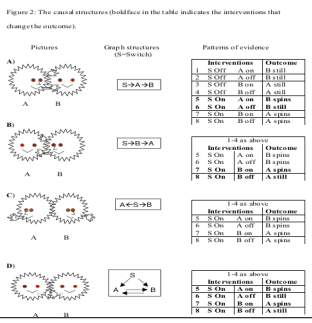


Figure 2: The causal structures (boldface in the table indicates the interventions that change the outcome).

Pictures | Graph structures (S=Switch) | Patterns of evidence

A)

	Interventions	Outcome
1	S OFF A on	B still
2	S OFF A off	B still
3	S OFF B on	A still
4	S OFF B off	A still
5	**S On**	**A on**	**B spins**
6	**S On**	**A off**	**B still**
7	S On	B on	A spins
8	S On	B off	A spins

S→A→B

B)

	1–4 as above	
	Interventions	Outcome
5	S On	A on	B spins
6	S On	A off	B spins
7	**S On**	**B on**	**A spins**
8	**S On**	**B off**	**A still**

S→B→A

C)

	1–4 as above	
	Interventions	Outcome
5	S On	A on	B spins
6	S On	A off	B spins
7	S On	B on	A spins
8	S On	B off	A spins

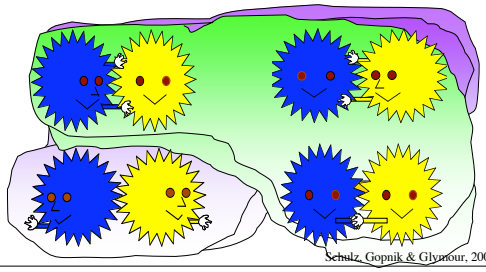
A←S→B

D)

	1–4 as above	
	Interventions	Outcome
5	**S On**	**A on**	**B spins**
6	**S On**	**A off**	**B still**
7	**S On**	**B on**	**A spins**
8	**S On**	**B off**	**A still**

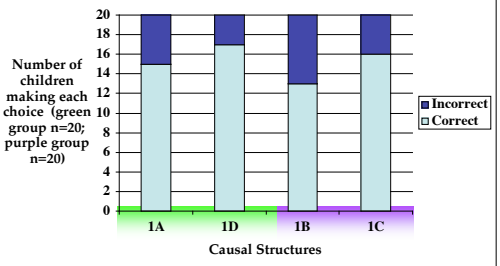
Experiment 2

- 40 preschool children (mean age: 4;8) were randomly assigned to one of two groups.



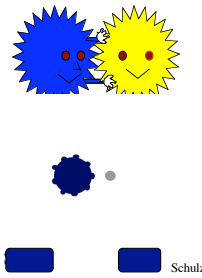
Schulz, Gopnik & Glymour, 2007

Predicting the structure from patterns of evidence



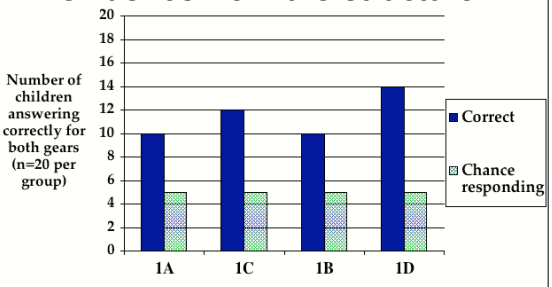
Schulz, Gopnik & Glymour 2007

Predicting evidence from structure



Schulz, Gopnik & Glymour, 2007

Predicting patterns of evidence from the structure



Schulz, Gopnik & Glymour, 2007

Results

- Preschool children can use interventions and the resulting patterns of conditional dependence and independence to learn causal structure.
- Preschool children can use knowledge of causal structure to predict the patterns of evidence that will result from interventions.

Schulz, Gopnik & Glymour, 2007

Experimentation

- In Experiments 1 and 2, the children were given the relevant patterns of independence and dependence. Would children be able to discover this evidence on their own?

Children's responses in Experiment 3

Children generating complete (2), partial (1), or no (0) evidence in each condition	**2**	**1**	**0**
Singles – Causal Chain (n = 12)	6 (50)	2 (17)	4 (33)
Dyads – Causal Chain (n = 12)	12 (100)	0 (0)	0 (0)
Dyads – Common Cause (n = 16)	10 (62)	4 (25)	2 (13)

Pictures

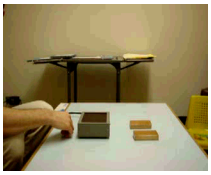
Children choosing each picture (of those who generated complete evidence)	**Correc chain**	**Incorrect chain**	**Common cause**
Causal Chain (n = 18)	7 (39)	1 (5)	10 (55)
Common Cause (n = 10)	0 (0)	1 (10)	90 (100)

Study 2. Can conditional probabilities override spatial constraints?

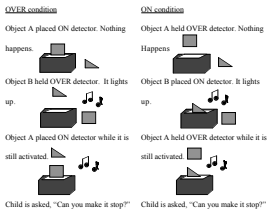
- Is spatial contact a necessary condition for causality?
- Michotte, Leslie, Scholl
- The remote
- Pit spatial contact against covariation and probability.
- Examine integration of prior knowledge and new evidence.

Kushnir & Gopnik (Developmental Psychology, 2007)

– Baseline Condition- Strong prior preference for contact: 81% make contact between block and toy when asked to "make it go" with no prior training.



Covariation condition



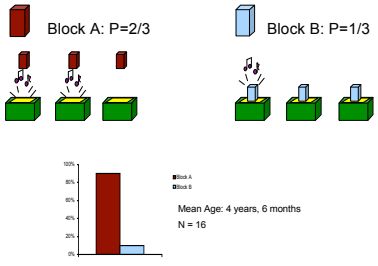
Results

	On Condition	Over Condition
On	11	1
Over	0	8
Other	4	6

Probabilistic Strength = Causal Strength?

- Adults make inferences about causal *strength* based on probabilistic evidence (Cheng, 1997; Waldman & Hagmayer, 2001).
- Children make inferences about causal *structure* based on deterministic evidence (Bullock, Gelman & Baillargeon, 1982; Gopnik, Sobel, Schulz & Glymour, 2001).
- Do children use probabilities to infer causal strength?
- How do their judgments of probabilities interact with other causal cues, such as spatial contiguity?

Probabilistic Strength = Causal Strength?



Causal Strength Question: "Which one works best?"

Probabilistic Strength = Causal Strength?

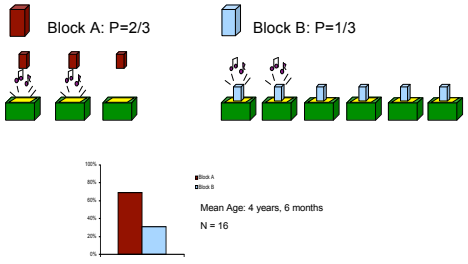
- Four-year-olds equate frequency of co-occurrence with causal strength in spite of conflicting perceptual information.
- Frequency vs. true probability (Aslin et al)

$$P(Activation \mid Object) = \frac{\#(Actvation \cap Object)}{\#(Object)}$$

Frequency of positive instances only

Frequency of both positive and negative instances

Probabilistic Strength = Causal Strength?



Causal Strength Question: "Which one works best?"

Prior Knowledge and New Evidence

- Better performance on the "ON" condition than the "OVER" condition".

Study 3. Using covariation to infer personality traits. Seiver Gopnik, and Goodman, 2006.

- Can children use covariation to infer real theories?
- Can children use covariation to infer new variables or causal schemata?
- Can children use probabilistic covariation?

Attribution Theory and Causal Inference

- Does Bayes net logic about abstract causes apply to intuitive theories of social cognition?
- Attribution theory - explaining action in terms of traits or situations
- Cross-cultural differences Peng & Morris, Dweck
- Intuitive theories
- Attribution and covariation Kelley, Morris and Lahrick

Children's theories of traits (Dweck)

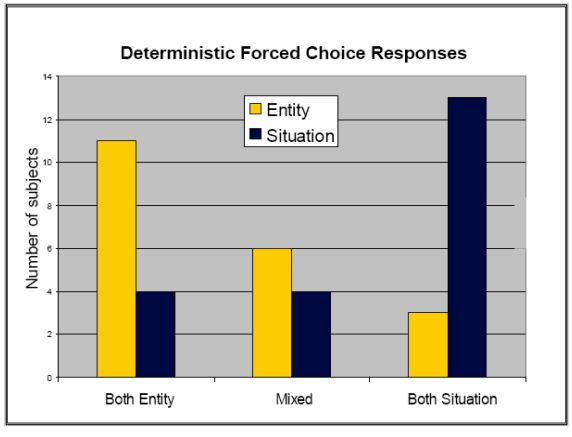
- By 4 children can understand trait terms (Heyman et al)
- Children don't explain actions in terms of traits until 7 or 8.
- Could children use conditional probability evidence to infer traits?

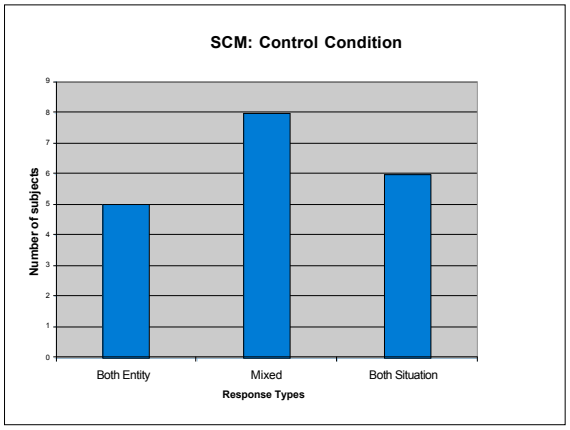
Study 1.Test conditions: deterministic

Entity Condition	Situation 1	Situation 2
Doll 1	plays (4/4)	plays (4/4)
Doll 2	won't play (0/4)	won't play (0/4)

Situation Condition	Situation 1	Situation 2
Doll 1	plays (4/4)	won't play (0/4)
Doll 2	plays (4/4)	won't play (0/4)

Control Condition	Situation 1	Situation 2
Doll 1	plays (4/4)	
Doll 2		won't play (0/4)



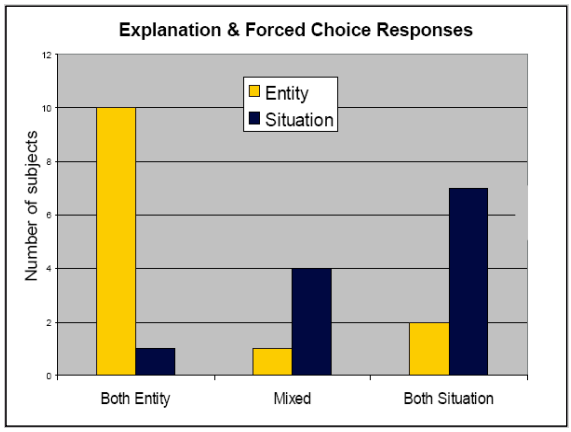


Results of Study 1

- Question: Why did she play/not play.Is it because she is the kind of person who does brave things, or is it because the situation is safe to play on? (or scared/dangerous)
- Children in the entity condition were more likely to endorse the 'kind of person' explanation for both dolls than in the situation condition
- Children in the situation condition were more likely to endorse the situation explanation for both dolls than in the entity condition

Study 2

- Participants: 24 4-year-olds
- Same procedure as Study 1
- Open ended question (Why did she do it?). Inferring a novel unobserved variable.
- Asked to predict to novel situation or person. Inferring a causal scheme.



Results of Study 2

Entity condition:

- Spontaneous explanations significantly more likely to be about the person (especially age and size) than the situation.
- Significantly more person explanations in the entity condition than in the situation condition
- Most children correctly predicted the behavior of the dolls in a novel situation

Results of Study 2

Situation Condition
- Significantly more situation explanations than in the entity condition

- Trend to produce more situation explanations than person explanations

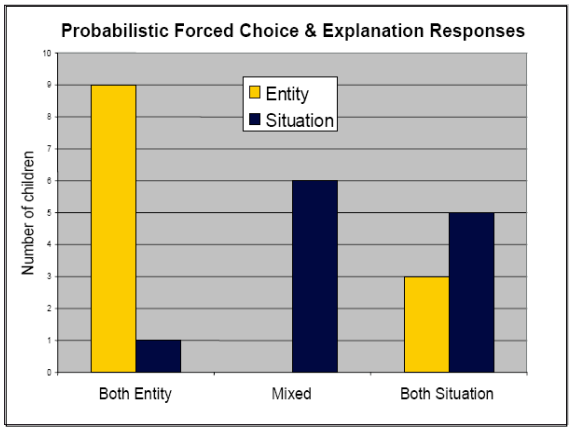
- Did not correctly predict a novel doll's behavior in the situations

Study 3 Test conditions: probabilistic

Entity Condition	Situation 1	Situation 2
Doll 1	plays (3/4)	plays (3/4)
Doll 2	won't play (1/4)	won't play (1/4)

Situation Condition	Situation 1	Situation 2
Doll 1	plays (3/4)	won't play (1/4)
Doll 2	plays (3/4)	won't play (1/4)

Control Condition	Situation 1	Situation 2
Doll 1	plays (6/8)	
Doll 2		won't play (2/8)



Summary of Children's Learning Studies

Causal Structure

Evidence

	One-link	Two-link	Complex	Unobserved
Deterministic Covariation		8 months Sobel 2006 24 months Sobel 2006 30 months Gopnik 2001	?	?
Probabilistic Covariation	4 years Kushnir 2007	4 years Seiver, 2007	?	4 years Schulz, 2006 Seiver 2007
Intervention + Covariation	9 months Meltzoff 1988	4 years Gopnik, 2004	4 years Schulz, 2007	4 years Gopnik, 2004
Bayesian Prior Knowledge	4 years Kushnir 2007	4 years Sobel, 2004 Baraff 2006	?	?

Further Directions

- Complex Causal Structure
- Novel Variables
- Higher-Order Generalizations - e.g. HBN

Further Directions

- Experimental Investigations
- Deterministic Experimenters Versus Probabilistic Data Miners
- Eberhardt and Active Learning

Further Directions

- Statistical Learning
- Relations between Frequency, Event Categorization and Probability

Conclusion

Yes, damn it, they really ARE little scientists !