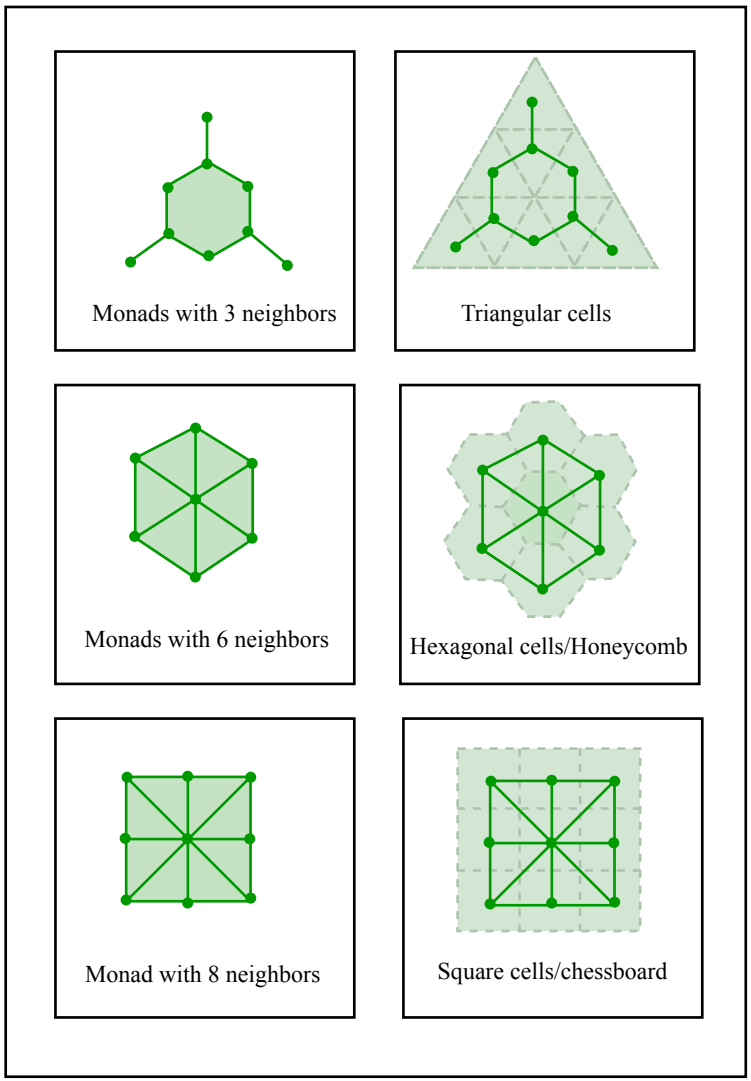
Theories of space:

"everything interesting was once philosophy."



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Please see:
Karch, A., and L. Randall. "Relaxing to three dimensions."
Phys Rev Lett 95, no. 16 (October 14, 2005):161601. *Epub* October 10 2005.

Figures courtesy of MIT OCW.

What do we know about space and how do we come to know it?

- Theories about space
- Possible ways of encoding space and objects
- Recent research on reorientation in humans and other species

What do we know about space and how do we come to know it?

- Theories about space
  - what type of space are we, as psychologists, interested in?

what type of space are we interested in?

psychological space **the world as it is**

absolute **relative** what is its nature?

absolute space:
•exists distinct from the objects

how do we come to know it?

a priori **learned** **learned**

Kant

Newton, Leibniz, Berkeley

What do we know about space and how do we come to know it?

- Theories about space
  - what type of space are we, as psychologists, interested in?
  - philosopher's views

Psychological space as relative and learned

- Newton:
  - Truly, space is absolute; however it is inaccessible to our senses, so we learn a relative psychological space.
    - “From positions and distances of things from any body considered immovable, we define all places... we estimate motions ....”

Psychological space as relative and learned

- Berkeley:
  - The physical world does not exist apart from minds. Everything is either a sensation produced by the mind, or a sensation impressed on us by God.
    - Our notions of space and distance derive from TACTILE information.

Psychological space as innate and absolute

- Kant
  - Space is absolute, but it is not a property of the physical world; rather it is an innate organizing principle of mind.
    - "Space was a *way* of perceiving, not a thing to be perceived." – (O'Keefe & Nadel)

The role of psychology :)

“Kant can be construed, albeit in the face of his own vigorous denials, as providing the basis for dividing the study of the natural world into physics and psychology.

The role of psychology is to describe the innate features of the minds of different organisms which have evolved to match certain aspects of the physical and external universe, and the way in which the physical universe interacts with the mind to produce the phenomenal world.”

- The Hippocampus as a Cognitive Map O’Keefe and Nadel

What do we know about space and how do we come to know it?

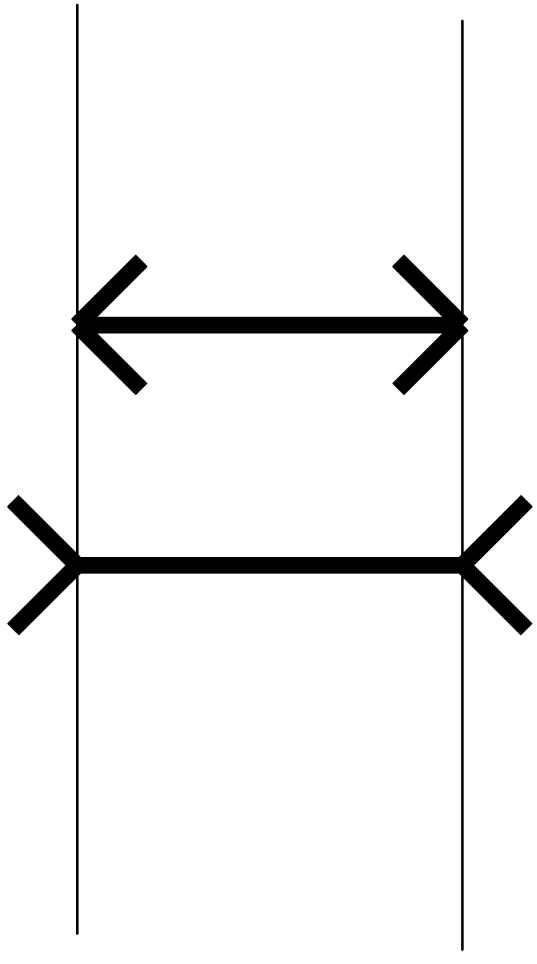
- Theories about space
  - what type of space are we, as psychologists, interested in?
  - philosopher's views
  - developmental theories of space

A theory of the development of psychological space must account for

- perception
  - perceptual invariances, e.g. size invariance, translation invariance
    - sensations do not map uniquely onto perceptions

A theory of the development of psychological space must account for

- perception
  - perceptual invariances, e.g. size invariance, translation invariance
    - sensations do not map uniquely onto perceptions
  - illusions, e.g. of length
    - our perceptions are not always accurate
      - even when we know we're wrong



A theory of the development of psychological space must account for

- perception
- known neuroanatomy and function
  - e.g. retinal images are non-Euclidean
- behavior
  - abilities, changes in abilities
  - failures

A theory of the development of psychological space must account for

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Piaget's constructivism:

a developmental theory as applied to children's understanding of space

- Review: the two tenets:
  - assimilation (a form of generalization)
  - accommodation (modification of assimilation schemes.
- We start off with very little – sensori-motor patterns and the ability to perceive light.
- First we must individuate objects,
- ***Only after*** can we form our first concept of space, by acting on objects

For Piaget, object individuation came before attaining a concept of space

- However...
  - subsequent work led Bower to conclude the following about young infants' object perception:
    - "[they] ignore features to such an extent that I would suggest they respond not to objects but to movements. Similarly I would suggest that they respond not to stationary objects but to moving objects." (Bower, 1971)
  - see Susan Carey's work on the role of motion in object individuation
- What is the ontogeny of human concepts of space?

What do we know about space and how do we come to know it?

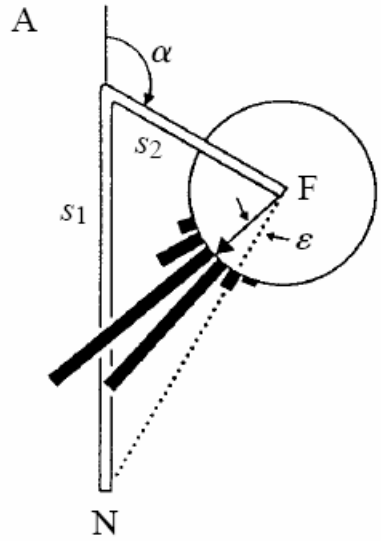
- Theories about space

- Possible ways of encoding space and objects

Ways of coding space

- with respect to self, “egocentric”
  - motor pattern, “response learning”
  - using metric (distance and direction) information with respect to self
    - e.g “dead reckoning”

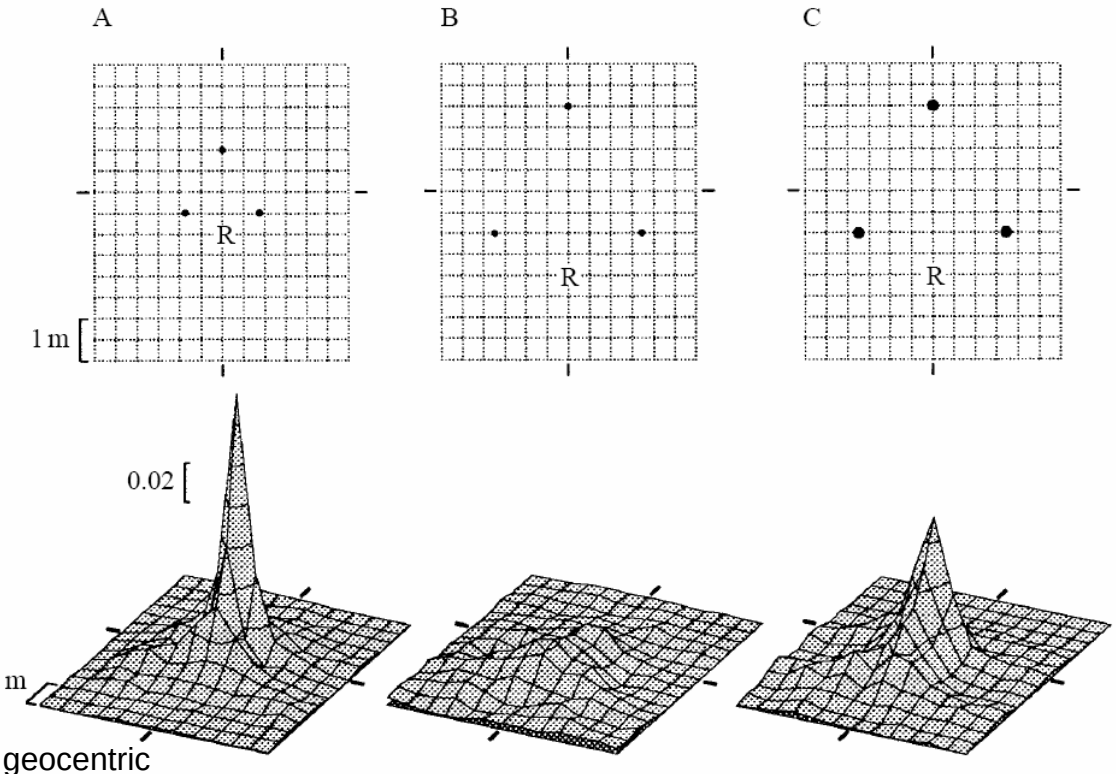
Fig. 3. Path integration in ants *Cataglyphis fortis*. (A) Experimental arrangement and result (example given for α=120°). Ants trained along the angular route s_1,s_2 from the nest (N) to a feeder (F) are captured at F and released in an open test field. (B) Error angles (ε) exhibited by the ants for different training angles (α). Mean values and standard deviations; N=1412. The dashed line represents the prediction of a non-trigonometric integration model. Data from Müller and Wehner (1988).



dead reckoning in the desert ant

snapshot matching: desert ant's use of landmarks.

Wehner, Michel & Antonsen, 1996



Figures from:
Wehner, R., B. Michel, and P. Antonsen.
"Visual navigation in insects: coupling of egocentric and geocentric information." *J Exp Biol* 199, no. Pt 1 (1996): 129-40.
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Ways of coding space

- with respect to self, “egocentric”
- with respect to the environment, “geocentric”
  - topology
    - a sense of the macroscopic shape of the environment

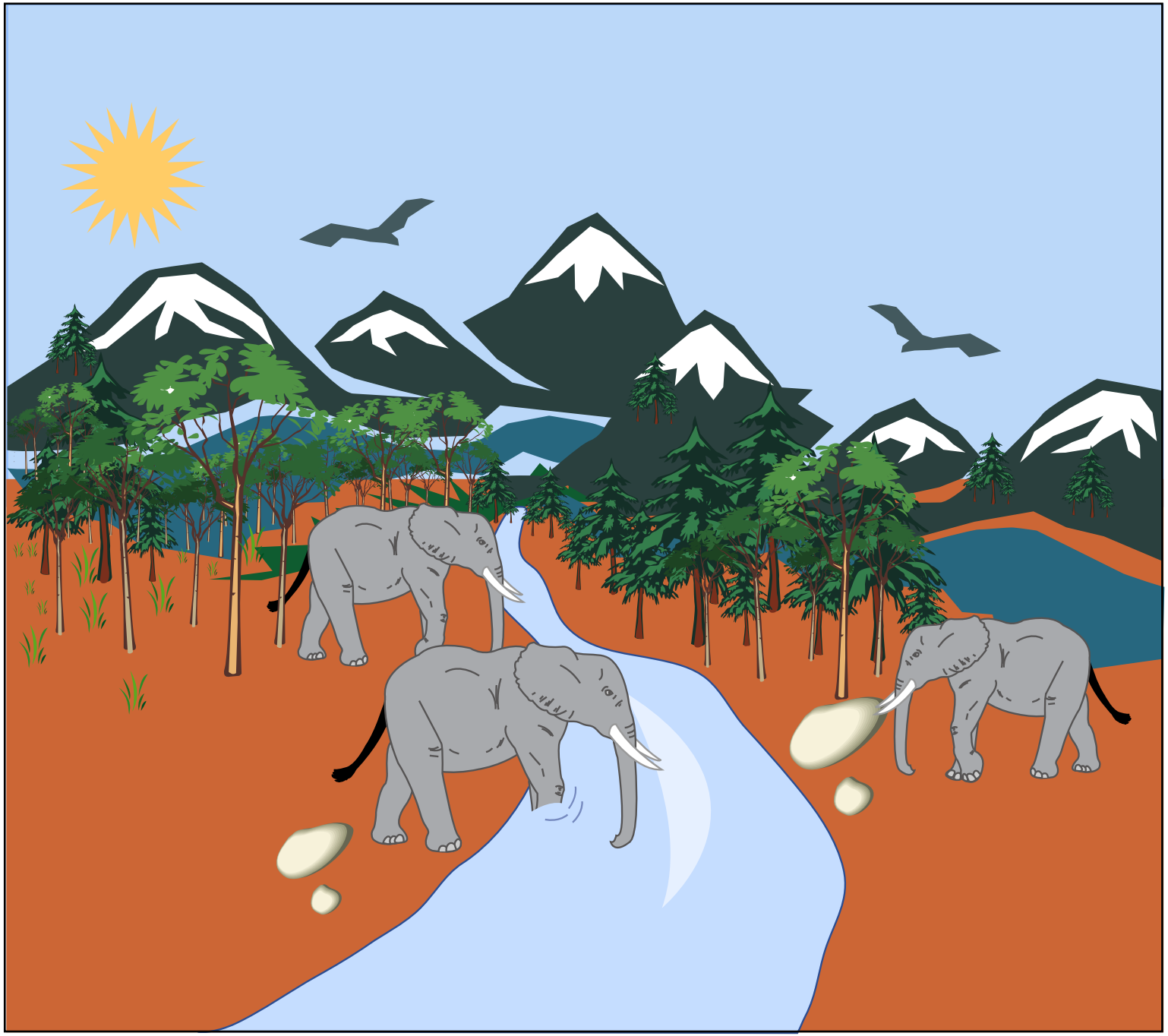


Illustration courtesy of MIT OCW.

Ways of coding space

- with respect to self, “egocentric”
- with respect to the environment, “geocentric”
  - topology
    - a sense of the macroscopic shape of the environment
  - routes, or cue learning
    - S-R behaviour
  - maps, or “place learning”
    - dependent on the hippocampus

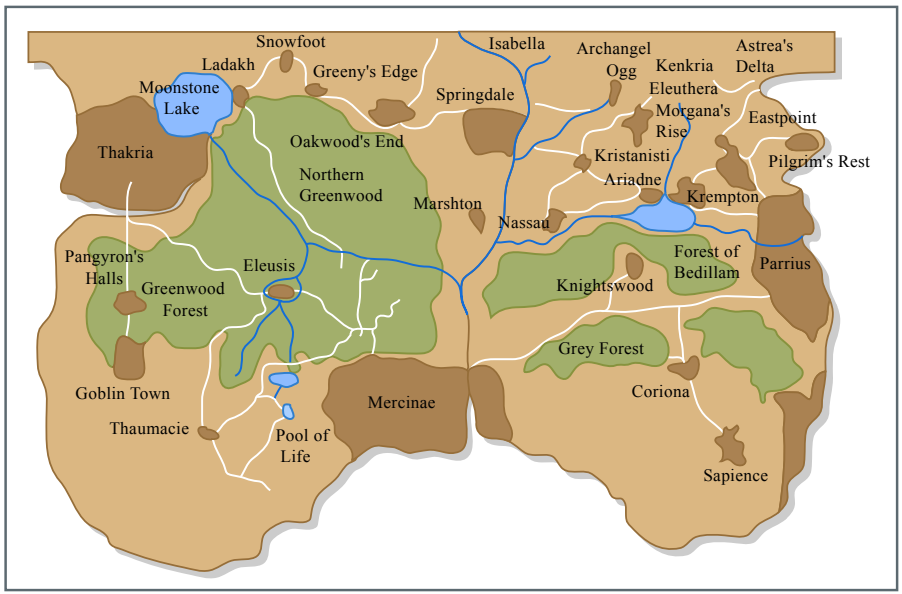
routes vs. maps

routes vs. maps

impatient_newbie_13 yells, “Can someone plz help me???? How do I do the elf quest? I need some gold. SOMEONE plz help me!!”

you tell impatient_newbie_13: “n, ne, e X 8, sw, up, up, wield sword right, kill monkey, d, d, take key, open cell, in, kiss elf”

routes vs. maps



Illustrations courtesy of MIT OCW.

What do we know about space and how do we come to know it?

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Ontogeny of Concepts of Space

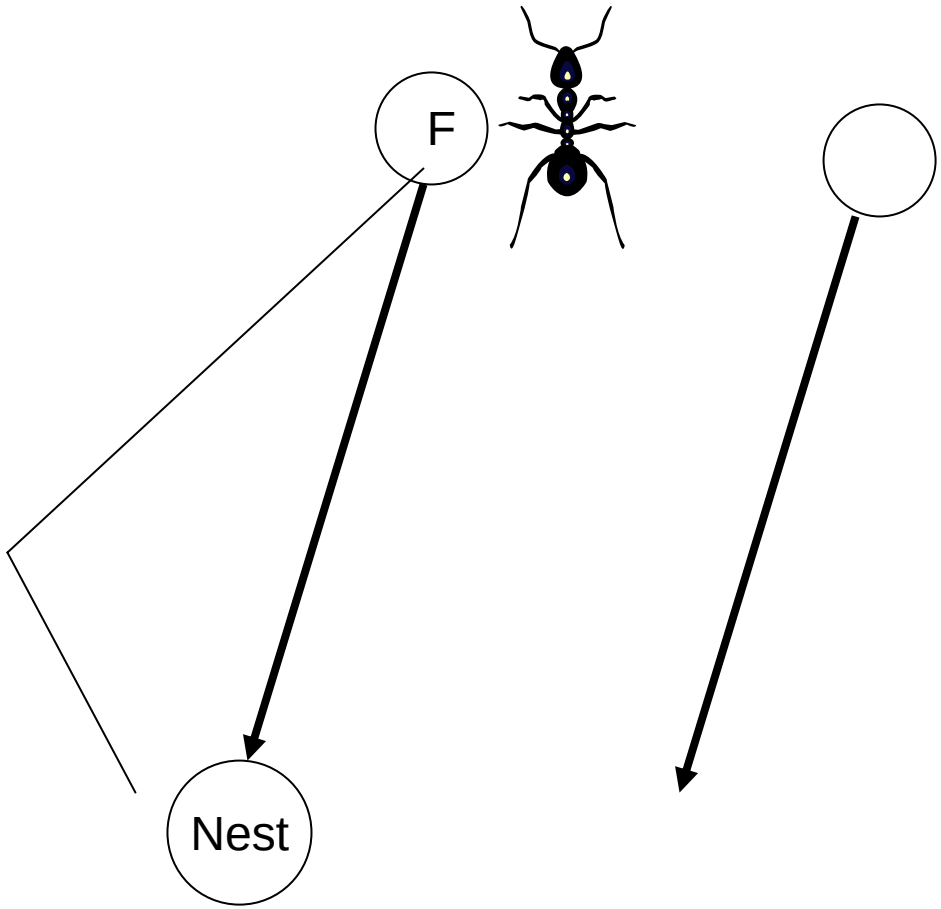
- What is the nature of our spatial behavior and spatial concepts at birth, and how do they change over development?

- What spatial representation systems do we share with other animals?

- Do we have multiple representation systems? If so which affect behavior most in what contexts?
  - "... perception is innate in the neonate but largely learned in the adult." – Frantz, 1965

Oriented Navigation

- When oriented , humans and other animals rely primarily on egocentric representations, notably “dead reckoning”, to determine the location of objects in space.
  - Cheng, Spelke
    - oriented or “thought to be oriented”


F
Nest

Ways of coding space: What can be used to reorient?

- ~~with respect to self, "egocentric"~~
- with respect to the environment, "geocentric"
  - topology
    - a sense of the macroscopic shape of the environment
  - routes, or cue learning
    - S-R behaviour
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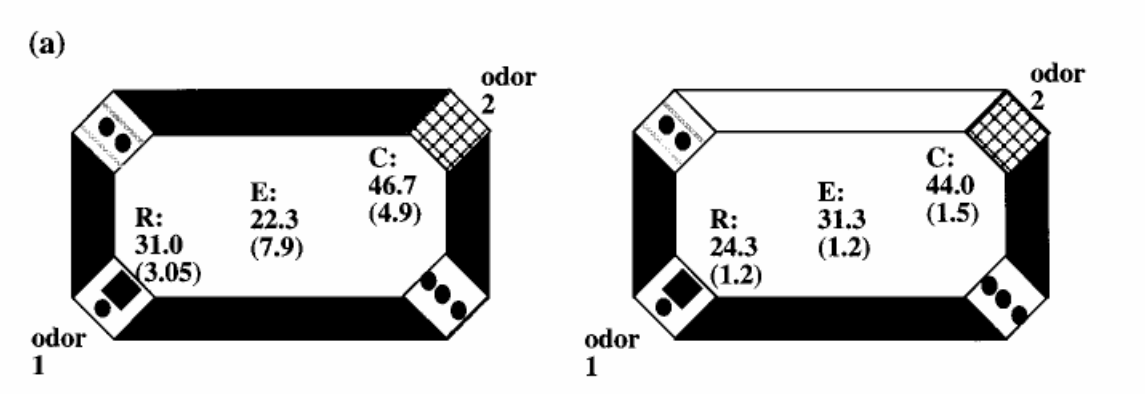
Disorientation studies...

- with rats
  - Cheng

Disorientation studies with rats



Cheng *et al.*

Disorientation studies...

- with rats
  - Cheng
- with humans
  - Spelke
  - Newcombe

Spelke Studies

18 – 24 mth. children
A Surprising Result!

Wang, Hermer & Spelke, 1999.

Figures removed due to copyright restrictions.
Please see:
Wang, R. F., L. Hermer, and E. S. Spelke. "Mechanisms of reorientation and object localization by children: a comparison with rats." *Behav Neurosci* 113, no. 3 (June 1999): 475-85.

Children can use
topological
cues to reorient.

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Please see:
Wang, R. F., L. Hermer, and E. S. Spelke. "Mechanisms of reorientation and object localization by children: a comparison with rats." *Behav Neurosci* 113, no. 3 (June 1999): 475-85.

Spelke: Children and adults

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Please see:

Fig 1b, 1c in Hermer-Vazquez, L., E. S. Spelke, and A. S. Katsnelson. "Sources of flexibility in human cognition: dual-task studies of space and language." *Cognit Psychol* 39, no. 1 (August 1999): 3-36.

Why are children (and rats), but not adults, failing to use a landmark cue to reorient?

- An encapsulated reorientation system that uses only geometric information. *Spelke*
  - Why does this make evolutionary sense?
    - landmark cues may be transient in the environment, whereas topological cues will tend to be stable and reliable
    - the same landmark can be seen from different perspectives, but the shape of the environment will change depending on perspective

Dual Task study: Spelke

- Perhaps the development of spatial language (“left” “right” “in” “out”) helps children use multiple sources of information to reorient.

- If the language system is key to helping adults combine geometric and non-geometric forms of information, a verbal distracting task should impair performance.

Verbal vs. Rhythm shadowing

Hermer-Vasquez, Katsnelson, Spelke, 1999

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Please see:

Fig 5b, 5d in Hermer-Vazquez, L., E. S. Spelke, and A. S. Katsnelson. "Sources of flexibility in human cognition: dual-task studies of space and language." *Cognit Psychol* 39, no. 1 (August 1999): 3-36.

- Verbal shadowing does not detract from the ability to notice landmark information or the ability to notice geometric information. It detracts from the ability to combine those two sources of information.

Figure removed due to copyright restrictions.

Please see:

Figs 6-7 in Hermer-Vazquez, L., E. S. Spelke, and A. S. Katsnelson. "Sources of flexibility in human cognition: dual-task studies of space and language." *Cognit Psychol* 39, no. 1 (August 1999): 3-36.

Spelke’s hypothesis

- Children have nonverbal systems for representing geometric properties of the environment, e.g short vs. long wall
- Children have noverbal systems for representing non-geometric properties, eg. colour and brightness
- Language allows children to combine these two types of information

However, two caveats: Caveat 1: Escaping Rats

- If rats are given aversive rather than appetitive reinforcement, they can use non-geometric/landmark cues for reorientation
  - *Golob & Taube 2002,*
  - *Dudchenko, Goodridge, Seiterle, Taube, 1997*

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Please see:

Fig 1 in Golob, E. J., and J. S. Taube. "Differences between appetitive and aversive reinforcement on reorientation in a spatial working memory task." *Behav Brain Res* 136, no. 1 (October 17, 2002): 309-16.

Caveat 1: Escaping rats
Why might this be?

- foraging vs. homing in on nest
  - different strategies called upon for different reinforcement types
- running vs. swimming
  - perhaps macroscopic environmental shape isn't a good cue in water (a bit unchanging).
- emotional vs. neutral memory
- stressed vs. less stressed
- availability of cues?

Caveat 2: Children in bigger rooms

- An uncontrolled variable has been room size.
  - *Learmonth, Nadel & Newcombe, 2002*
    - *large room = 8ft X 12ft*
    - *small room = 4ft X 6ft*
    - *Spelke room(square) = 6.56ft X 6.56ft X 6.56ft*
    - *Spelke room(rectangular) = ???*
    - *rat room = short wall is 2x length of rat*

Figure removed due to copyright restrictions.
Please see:
Learmonth, A. E., L. Nadel, and N. S. Newcombe. "Children's use of landmarks: implications for modularity theory." *Psychol Sci* 13, no. 4 (July 2002): 337-41.

Why should children succeed in a larger room?

- multiple strategies?

What changes allow older children and adults to succeed in a small room?

- spatial language?
- mature hippocampus?

Summary and Questions

- Children < 5yo in small rooms and rats with appetitive reinforcement do NOT appear to use exclusively topological information to reorient.

- However, rats with aversive reinforcement, older children, children in larger rooms, and adults can use both topological and landmark information to reorient.

- What does this say for the “encapsulated module” idea? Can we still believe it? Do we need to modify or discard it?

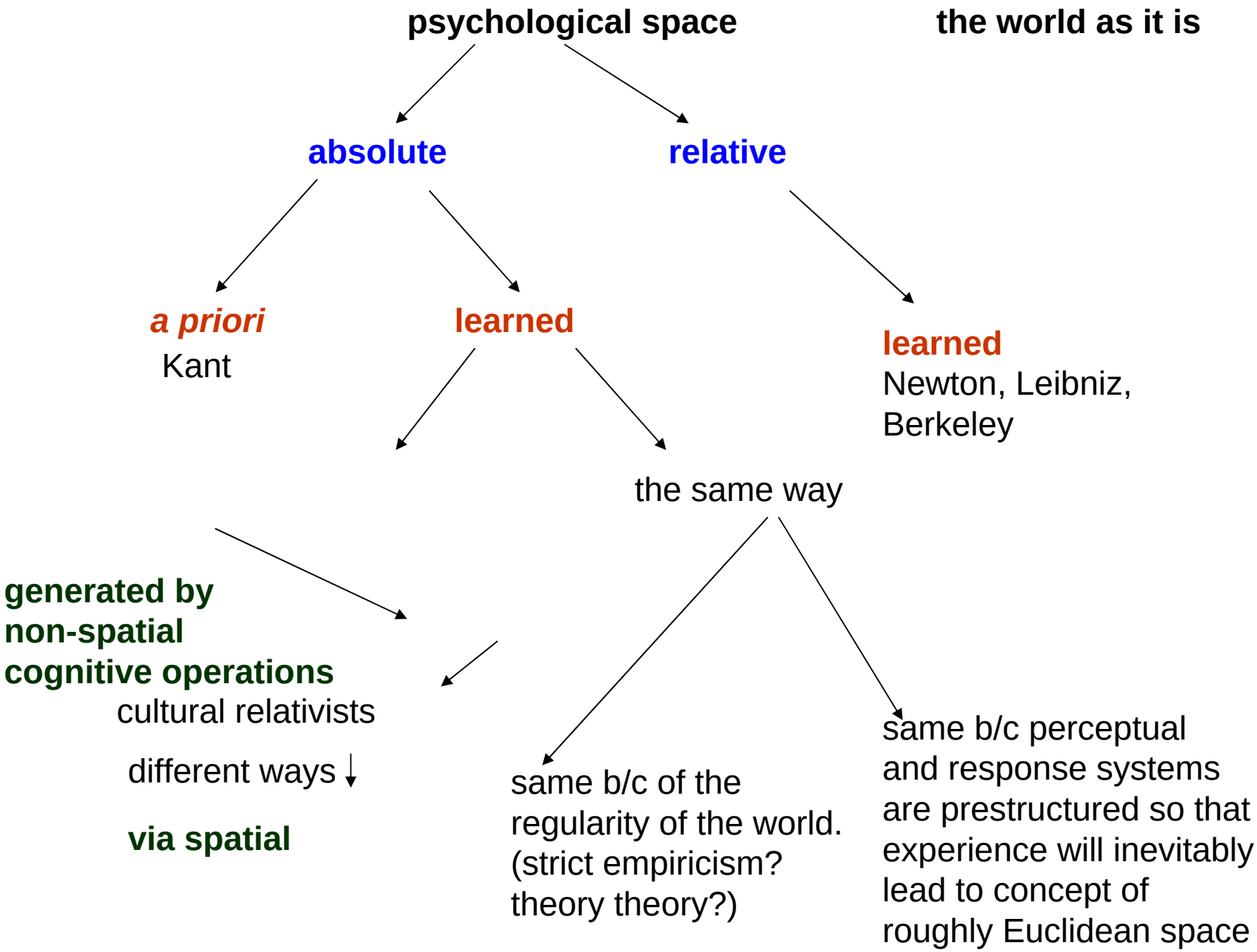
- In any event, children's ability to use SALIENT landmarks to reorient is surprisingly fragile.

Challenges to the “language mediated” theory

- rats succeed under some conditions (i.e. escape)
- preverbal children can succeed under some conditions (i.e. large room)

Summary and Questions

- It seems that humans, like other animals rely on an egocentric dead-reckoning system when oriented.
- When this system is disrupted by disorientation, humans rely ***primarily*** on macroscopic spatial, or 'topological', information – the general shape of an environment
- The ability of human children to use non-topological cues, like landmarks, for reorientation is fragile and affected by factors like openness or size of environment, and the ability to produce spatial language
- If the ability to produce spatial language is delayed because of a language specific disorder, will we see correspondingly delayed success at the types of reorientation tasks we've discussed?
- In manmade environments, like cities, what are the geometric properties of the environment? Are we equipped to reorient in a manmade environment given the type of information on which we primarily rely?
- What brain areas support reorientation in humans?
  - not place cells.
- What is the developmental trajectory of spatial reorientation systems and what are the contexts that cause us to rely on one or another?


psychological space
the world as it is
absolute
relative
a priori
Kant
learned
learned
Newton, Leibniz, Berkeley
the same way
generated by non-spatial cognitive operations
cultural relativists
different ways
via spatial
same b/c of the regularity of the world. (strict empiricism? theory theory?)
same b/c perceptual and response systems are prestructured so that experience will inevitably lead to concept of roughly Euclidean space

Disorientation procedures knock out:

- with respect to self, “egocentric”
  - motor pattern, “response learning”, ‘view dependent’
  - using metric information with respect to self, “dead reckoning”
    - constantly updated as self moves, and so subject to culmulative error
- with respect to landmarks, “geocentric”
  - proximal, coincident landmarks, “cue learning”
  - using distance/direction information w/ respect to far-away landmarks: "place learning“
    - shown to be dependent on “place cells” in the hippocampus (O’Keefe & Nadel, 1978)