# Lecture 2
# Developmental Robotics

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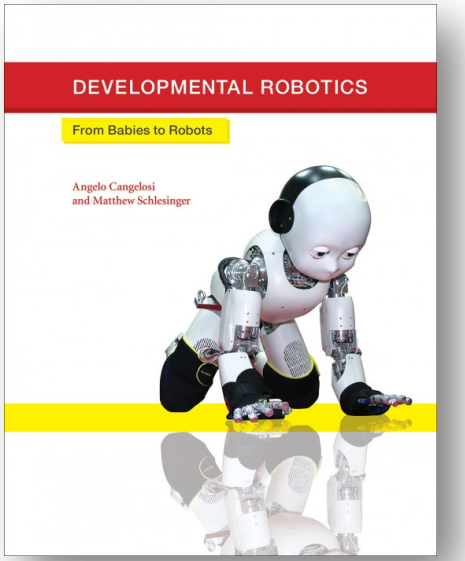
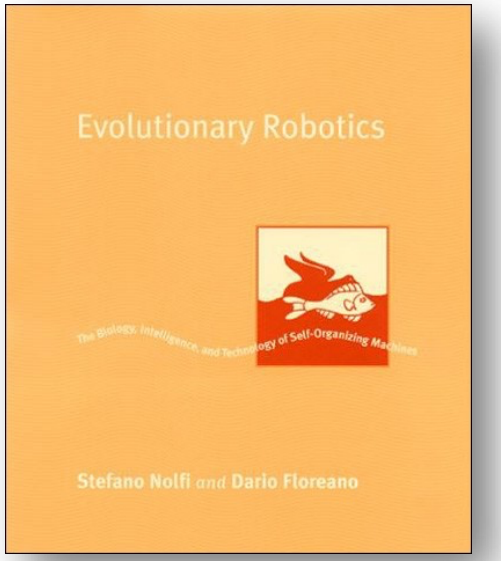
# Content

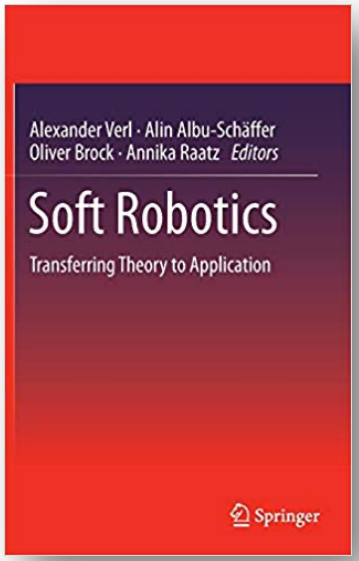
- First example of cognitive robotics
- Developmental Robotics
  - Direct inspiration from developmental psychology
- Six principles
  - Dynamical systems, phylogenetic-ontogenetic interaction, Embodiment, Intrinsic motivation
  - Incremental, non linear developmental stages and open ended learning

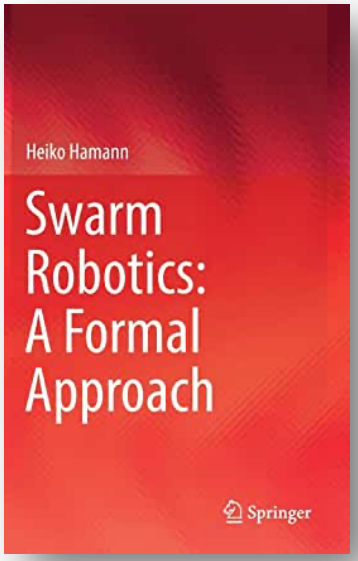
# Cognitive Robotics

- Cognitive Robotics Approaches
  - **Developmental Robotics** (Cangelosi & Schlesinger 2015)
  - Evolutionary Robotics (Nolfi & Floreano 2002)
  - Swarm Robotics (Dorigo et al. 2014; Hamann 2018)
  - Soft Robotics (Laschi et al. 2016; Veri et al. 2015)



# Developmental Robotics

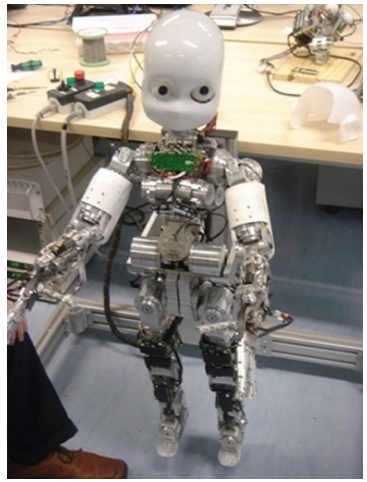
*Developmental Robotics is the interdisciplinary approach to the **autonomous design** of behavioral and cognitive capabilities in artificial agents (robots) that takes **direct inspiration** from the **developmental principles** and mechanisms observed in natural cognitive systems (children).*

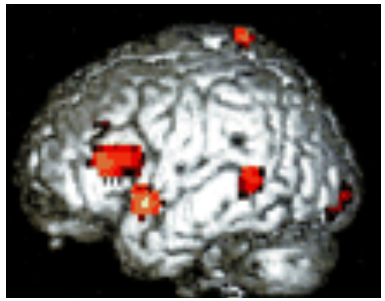
(Cangelosi & Schlesinger 2015)

Ethology

Computer science

Robotics



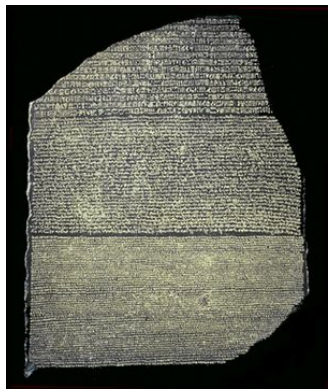


Neuroscience

Cognitive Developmental Robotics

Child Psychology

Cognitive Psychology



Linguistics

2015

2017

2018

2019

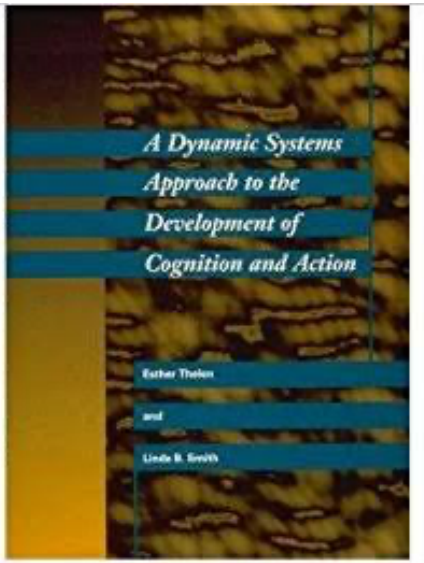

The MIT Press

# DevRob Principles

| | Principles | *Characteristics* |
|---|---|---|
| **1** | Development as a Dynamical System | *Decentralized system*<br>*Self-organization and emergence*<br>*Multicasuality*<br>*Nested timescales* |
| **2** | Phylogenetic and Ontogenetic Interaction | *Maturation*<br>*Critical period*<br>*Learning* |
| **3** | Embodied and Situated Development | *Embodiment*<br>*Situatedness*<br>*Enaction*<br>*Morphological computation*<br>*Grounding* |
| **4** | Intrinsic Motivation and Social Learning | *Intrinsic motivation*<br>*Value systems*<br>*Imitation* |
| **5** | Nonlinear, Stage-Like Development | *Qualitative stages*<br>*U-shape phenomena* |
| **6** | Online Open-Ended Cumulative Learning | *Online learning*<br>*Cumulative*<br>*Cross-modality*<br>*Cognitive bootstrapping* |

# Principle 1: Dynamical Systems

- Decentralized system
- Self-organization and emergence
- Multicausality
- Nested timescales




*Child development as the emergent product of the intricate and dynamic interaction of many decentralized and local interactions related to the child's growing body, brain and her environment* (Thelen and Smith 1994)

Thelen & Smith (1996). A dynamic systems approach to the development of cognition and action. MIT press.

# Principle 1: Dynamical Systems

Walking reflex: A primitive reflex that appears at birth. Babies move their legs rhythmically and alternatively when held upright over a flat surface.

Alternative stepping suddenly disappeared around 2 months old. *But …*


when the behavioral context was altered by submerging the infant's legs in the water, alternative stepping behavior *re*appeared !


The treadmill machine with a moving belt elicited well-coordinated leg movements !

Thelen & Smith (1996). A dynamic systems approach to the development of cognition and action. MIT press.

# Principle 2: Evolution and Learning

- Evolution: Phylogenesis
- Development: Ontogenesis
  - Maturation
  - Critical period
  - Learning

cf. Evolutionary Robotics Lecture

# Principle 3: Embodied and Situated

- Embodiment: Body-Brain-Environment interaction (Wilson 2002; Ziemke 2003)
- Situatedness: Learning in context (Clark 1997)
  - Enaction: Own model of the world (Vernon, 2010)
  - Morphological computation (cf. robot lectures)
  - Grounding (cf. language lecture)

Ziemke, T. (2003). What's that thing called embodiment?. In *Proceedings of the annual meeting of the cognitive science society* (Vol. 25, No. 25).

# Principle 4: Intrinsic Motivation and Social Learning

- Intrinsic motivation:
  - Curiosity, surprise, novelty-seeking, values, drives (Baldassarre & Mirolli 2013; Oudeyer & Kaplan 2009)

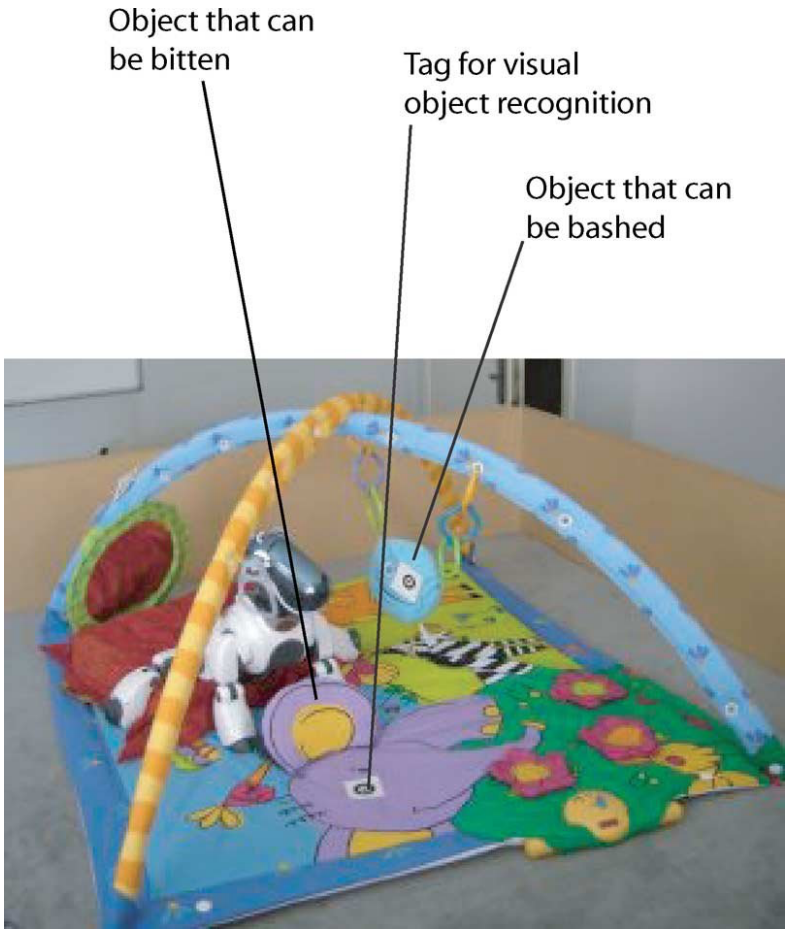
- Social learning and imitation
  - cf. Social and Human-Robot Interaction lecture

Baldassarre (2019). *Intrinsic motivations and open-ended learning*. Arxiv.

Oudeyer & Kaplan (2009). What is intrinsic motivation? *Frontiers in Neurorobotics*, 1, 6.

# Principle 4: Intrinsic Motivation and Social Learning

## Playground Experiment


www.pyoudeyer.com/curiosity-and-information-seeking-in-cognitive-development/

Oudeyer, P. Y., Kaplan, F., Hafner, V. V., & Whyte, A. (2005). The playground experiment: Task-independent development of a curious robot. *AAAI Spring Symposium on Developmental Robotics* (pp. 42-47). Stanford

# Principle 5: Non Linear, Stage Development

- Developmental milestones

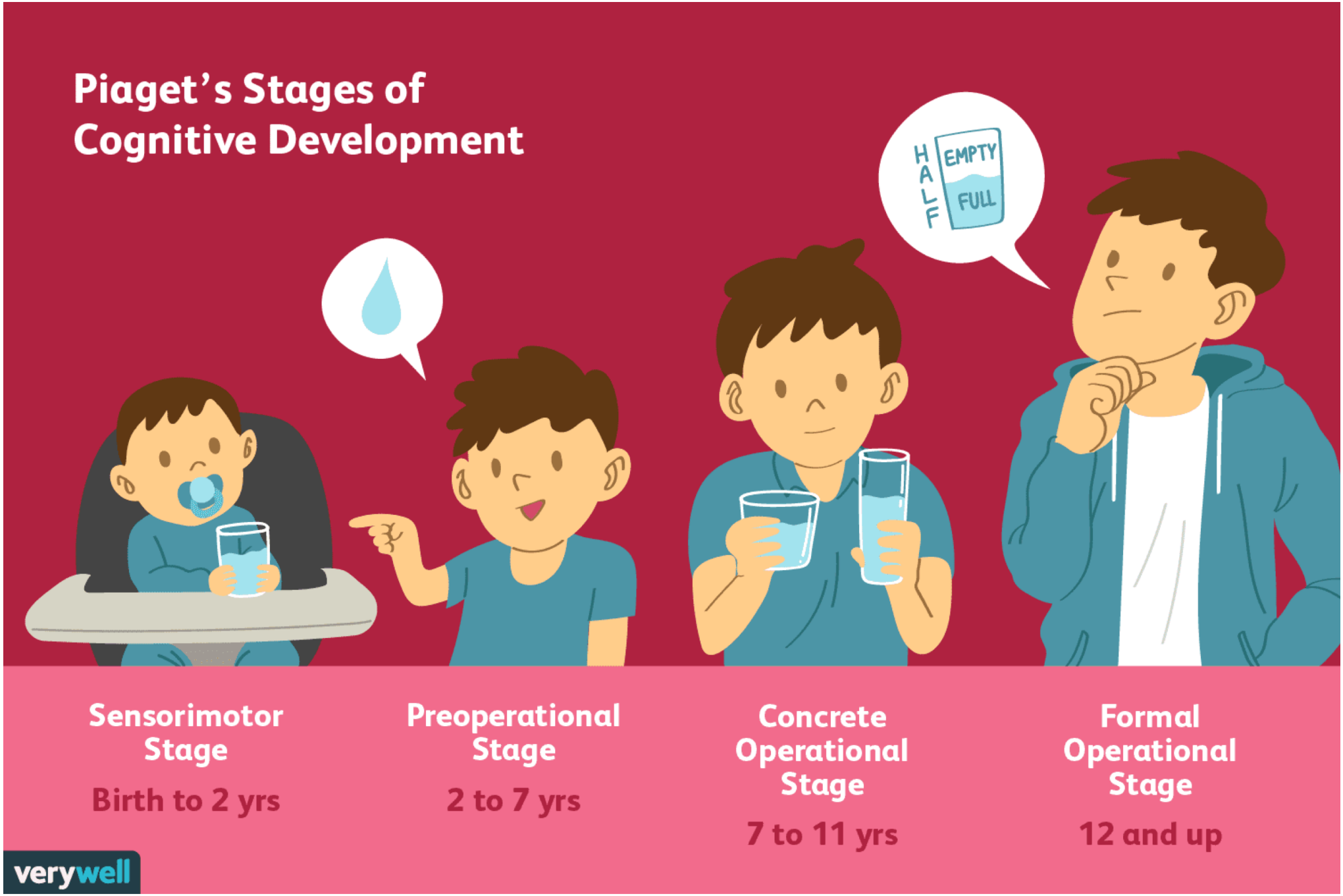
| months | behaviors | learning targets |
|---|---|---|
| 5 | hand regard | forward and inverse models of the hand |
| 6 | finger the other's face | integration of visuo-tactile sensation of the face |
| | observe objects from different viewpoints | 3-D object recognition |
| 7 | drop objects and observe the result | causality and permanency of objects |
| 8 | hit objects | dynamics model of objects |
| 9 | drum or bring a cup to mouth | tool use |
| 10 | imitate movements | imitation of unseen movements |
| 11 | fine grasp and carry objects to others | action recognition and generation, cooperation |
| 12 | pretend | mental simulation |

Asada et al. 2009

# Non Linear, Stage Development

- Developmental milestones
- **Qualitative Stages (Piaget)**
  - Genetic Epistemology Theory
  - 4 Stages

https://www.verywellmind.com/piagets-stages-of-cognitive-development-2795457

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# Piaget's Stages

## The Sensorimotor Stage

**Ages: Birth to 2 Years**

Major Characteristics and Developmental Changes:

- The infant knows the world through their movements and sensations
- Children learn about the world through basic actions such as sucking, grasping, looking, and listening
- Infants learn that things continue to exist even though they cannot be seen (object permanence)
- They are separate beings from the people and objects around them
- They realize that their actions can cause things to happen in the world around them

## The Preoperational Stage

**Ages: 2 to 7 Years**

Major Characteristics and Developmental Changes:

- Children begin to think symbolically and learn to use words and pictures to represent objects.
- Children at this stage tend to be egocentric and struggle to see things from the perspective of others.
- While they are getting better with language and thinking, they still tend to think about things in very concrete terms.

https://www.verywellmind.com/piagets-stages-of-cognitive-development-2795457

# Piaget's Stages

## The Concrete Operational Stage

**Ages: 7 to 11 Years**

Major Characteristics and Developmental Changes

- During this stage, children begin to thinking logically about concrete events
- They begin to understand the concept of conservation; that the amount of liquid in a short, wide cup is equal to that in a tall, skinny glass, for example
- Their thinking becomes more logical and organized, but still very concrete
- Children begin using inductive logic, or reasoning from specific information to a general principle

## The Formal Operational Stage

**Ages: 12 and Up**

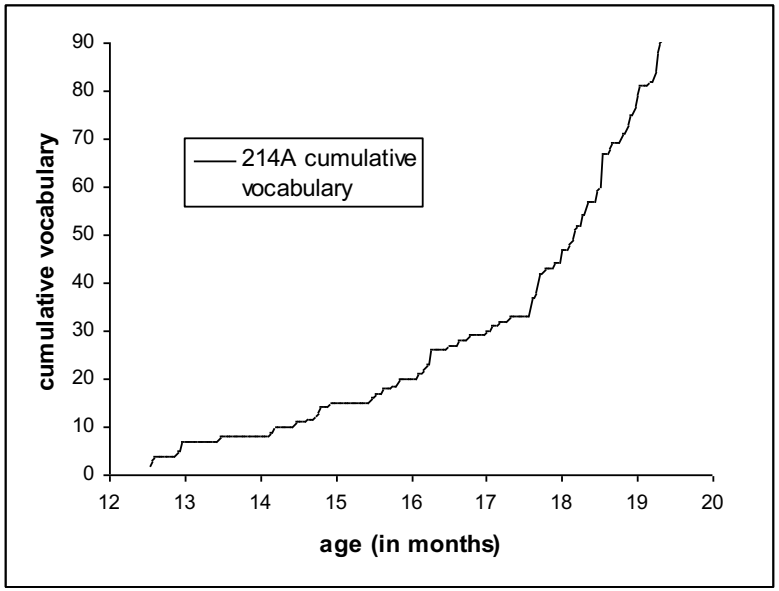
Major Characteristics and Developmental Changes:

- At this stage, the adolescent or young adult begins to think abstractly and reason about hypothetical problems
- Abstract thought emerges
- Teens begin to think more about moral, philosophical, ethical, social, and political issues that require theoretical and abstract reasoning
- Begin to use deductive logic, or reasoning from a general principle to specific information

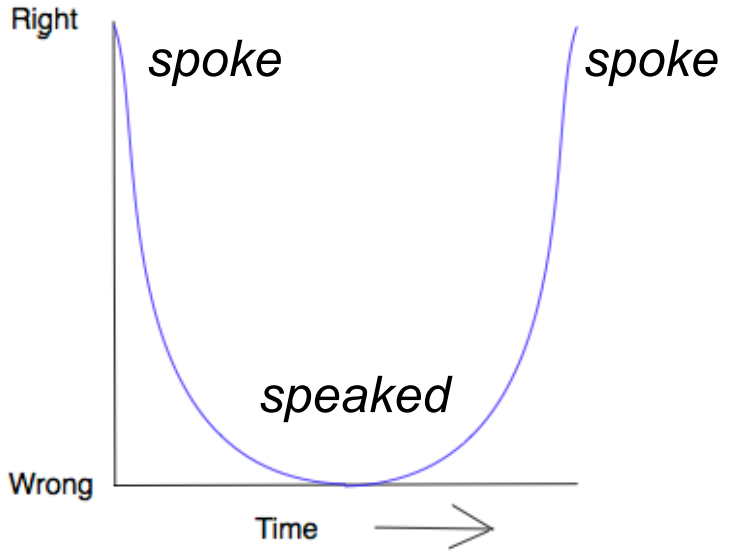
https://www.verywellmind.com/piagets-stages-of-cognitive-development-2795457

# Non Linear (U-shape) Development

- Developmental milestones
- Qualitative Stages (Piaget)
- **Non-linear development (U-Shape)**




Vocabulary spurt
Goldfield & Reznick 1990




English past tense
Carlucci & Case, 2003; Plunkett & Marchman 1991

# Principle 6:
# Online, Open Ended, Cumulative

(Linked to intrinsic motivation)

- Online learning
- Cumulative
- Cross-modality
- Cognitive bootstrapping

Baldassarre (2019). *Intrinsic motivations and open-ended learning*. Arxiv.

# Summary

- Developmental Robotics
  - Direct inspiration from developmental psychology
  - Six principles
  - Incremental, stages, development
  - Focus on intrinsic motivation

- Reading
  - Chapter 3, Cangelosi & Asada 2022