UMassAmherst

Always On: Cognitive Organization *and Programming* for Lifelong Cumulative Learning

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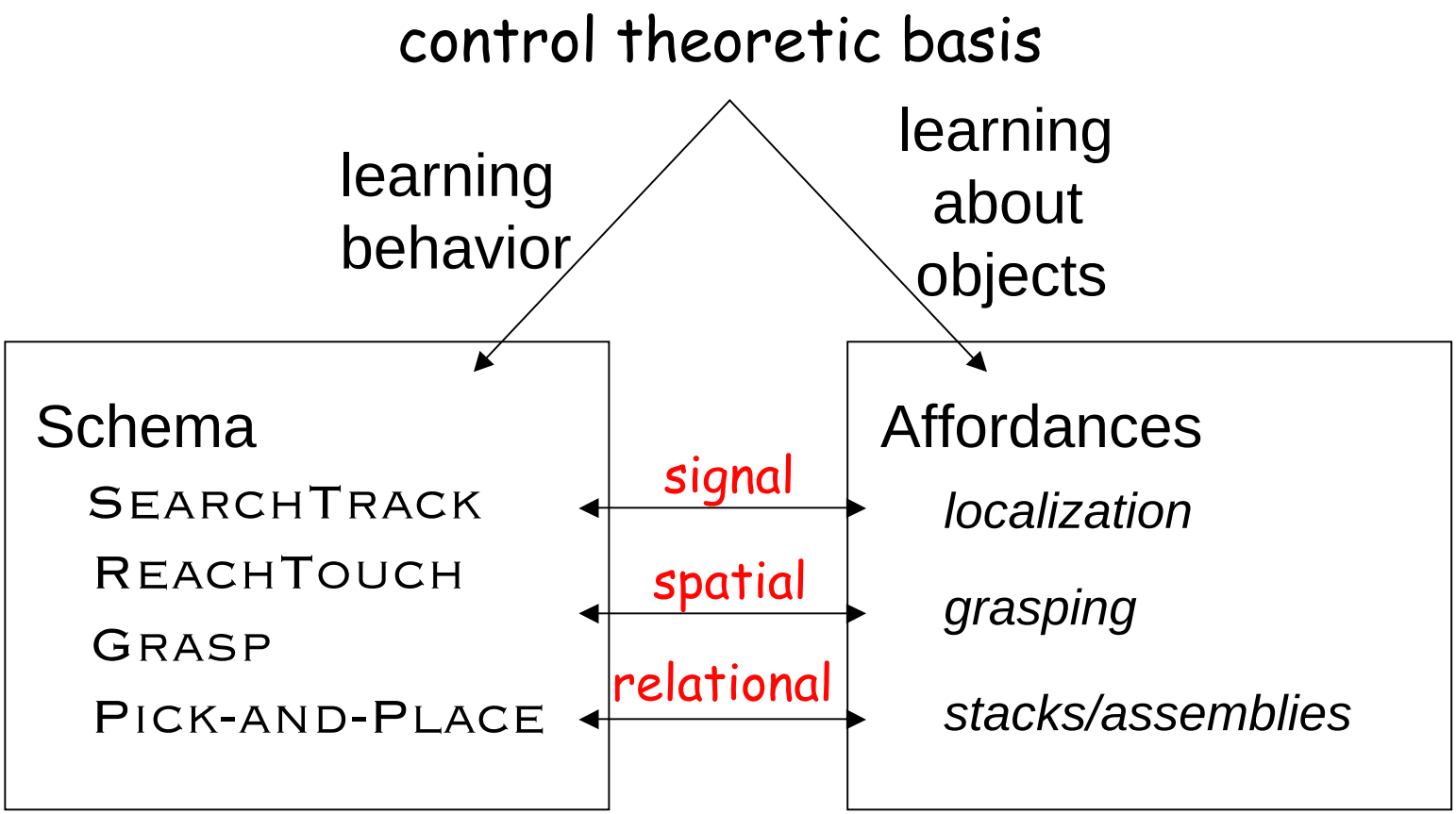
Proposition #1: *We're closer than you think*

Unbridled Optimism - robot mechanisms, sensors, low-level control, machine learning are all adequate for truly intelligent machines

What's missing is the incentive to *discover* and a cognitive organization that integrates a lifetime of experience!

for transfer, re-use, generalization, recognition, problem solving, and *dexterity*

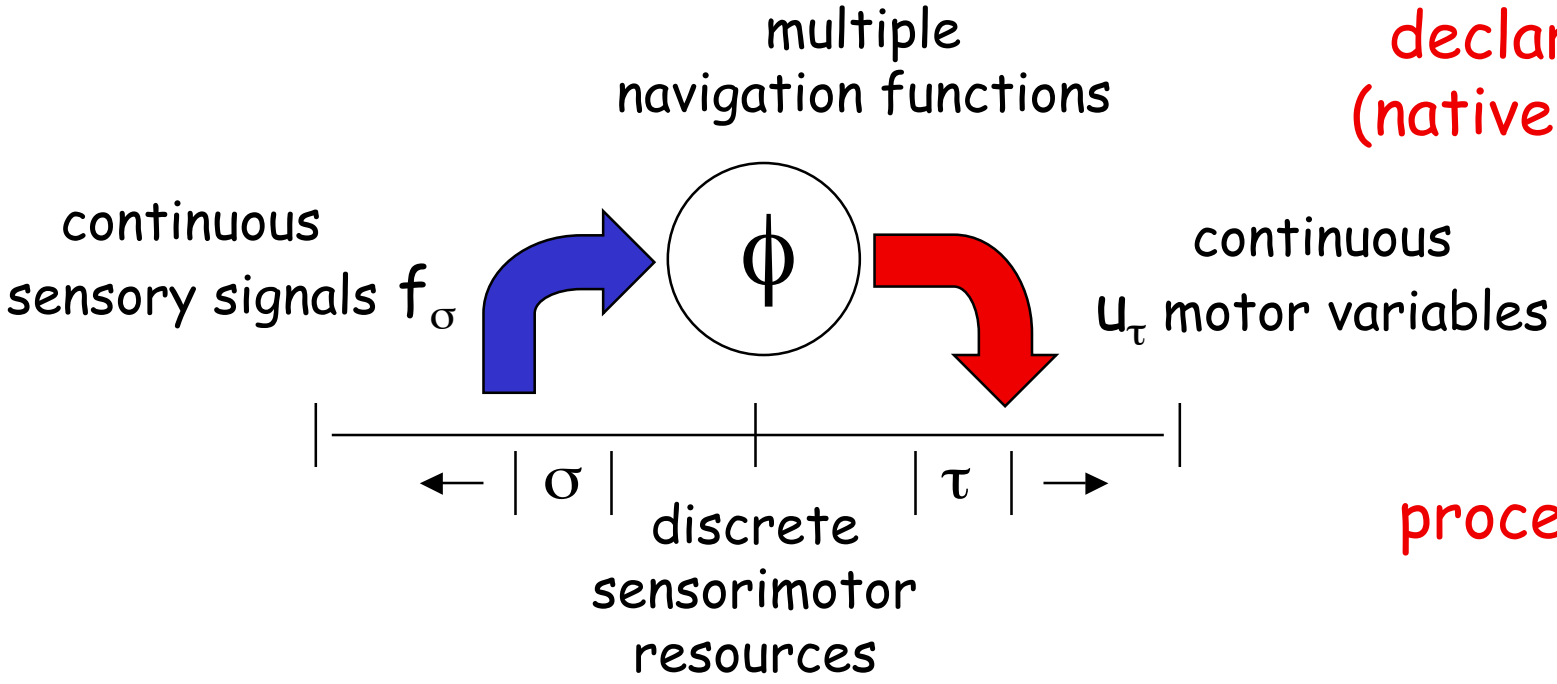
Representational Foundations



abstract domain-general behavior expertise with specific objects

Representational Foundations: The *Control Basis*

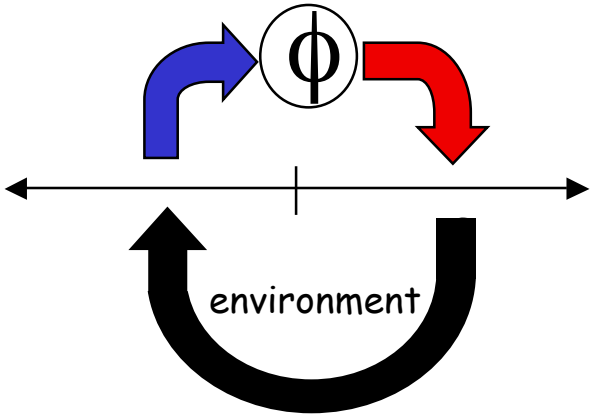
a control theoretic framework with built in *intentions*



typing - characteristic I/O types
supports multiple implementations

Manfred Huber

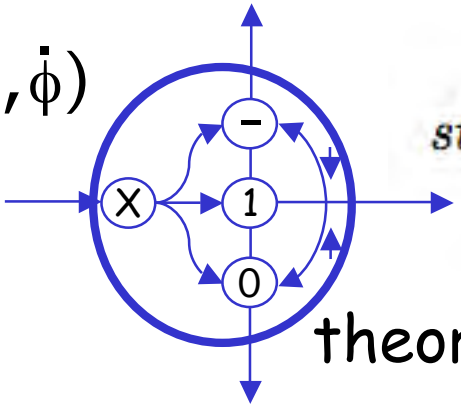
Action and State



action: $\Delta u_\tau \propto -\left(\frac{\partial \phi(f_\sigma)}{\partial u_\tau}\right)^{\#} \phi(f_\sigma)$

co-articulation

$p(\phi, \dot{\phi})$



$$state\left(\frac{\partial \phi(f_\sigma)}{\partial u_\tau}\right) = \begin{cases} X & \text{don't know/don't care} \\ - & \text{no reference } f_\sigma \text{ available} \\ 0 & \text{transient response} \\ 1 & \text{convergence/quiescence} \end{cases}$$

theorem proving for performance guarantees

state coarsely encodes the dynamic status of the control circuit

Proposition #2: *Autonomy*

rather than defining everything the robot should learn during every step of the programming process, provide the robot with an intrinsic inquisitiveness, curiosity, and motive for discovery

intrinsic motivation

evolution has selected primary reinforcers for exploration, play, and discovery that lead to cognitive development.

(Q-learning, no function approximation, ~25 trials)
no tasks, only play

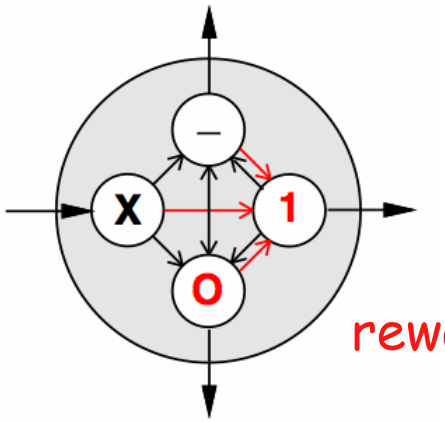
Affordances

all "action possibilities" latent in the environment, objectively measurable and independent of the individual's ability to recognize them, but always in relation to the actor and therefore dependent on their capabilities.

J.J. Gibson (1977), "The Theory of Affordances," In Perceiving, Acting, and Knowing, Eds. Robert Shaw and John Bransford.

Intrinsic Affordance Discovery Motivation

reward controllers that converge when tracking references derived from environmental stimuli

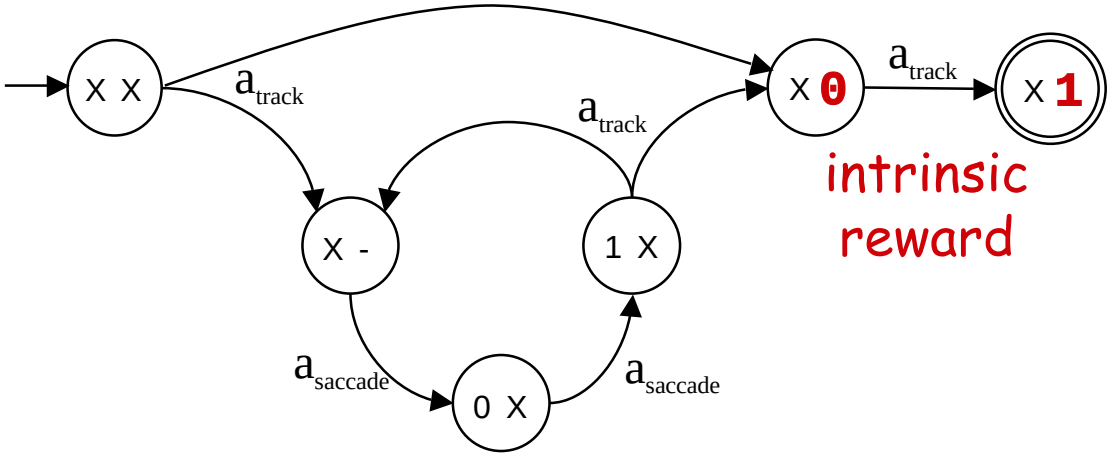


intrinsic reward

$$\propto Pr\left(\left(\left(\frac{\partial\phi(f_\sigma)}{\partial u_\tau}\right)^{t_{k-1}} \neq 0\right) \wedge \left(\left(\frac{\partial\phi(f_\sigma)}{\partial u_\tau}\right)^{t_k} = 0\right)\right)$$

Developmental Setting for Skill Learning:

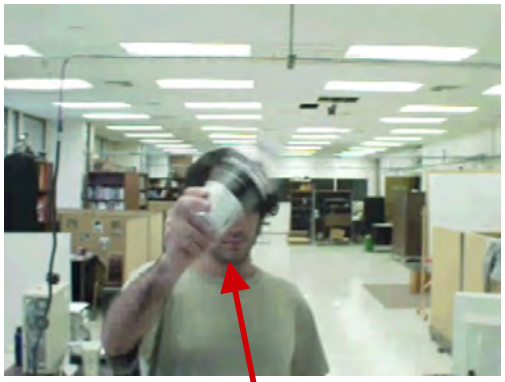
SearchTrack

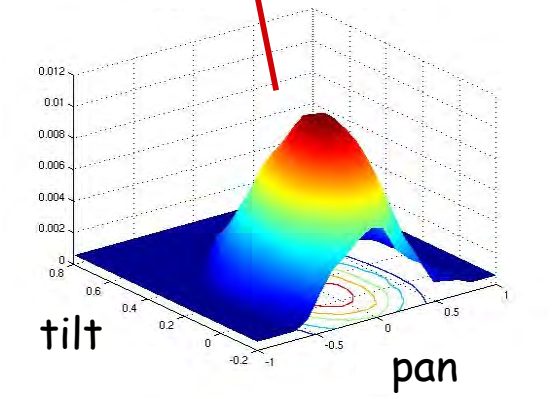


intrinsic reward

training context - 25 trials

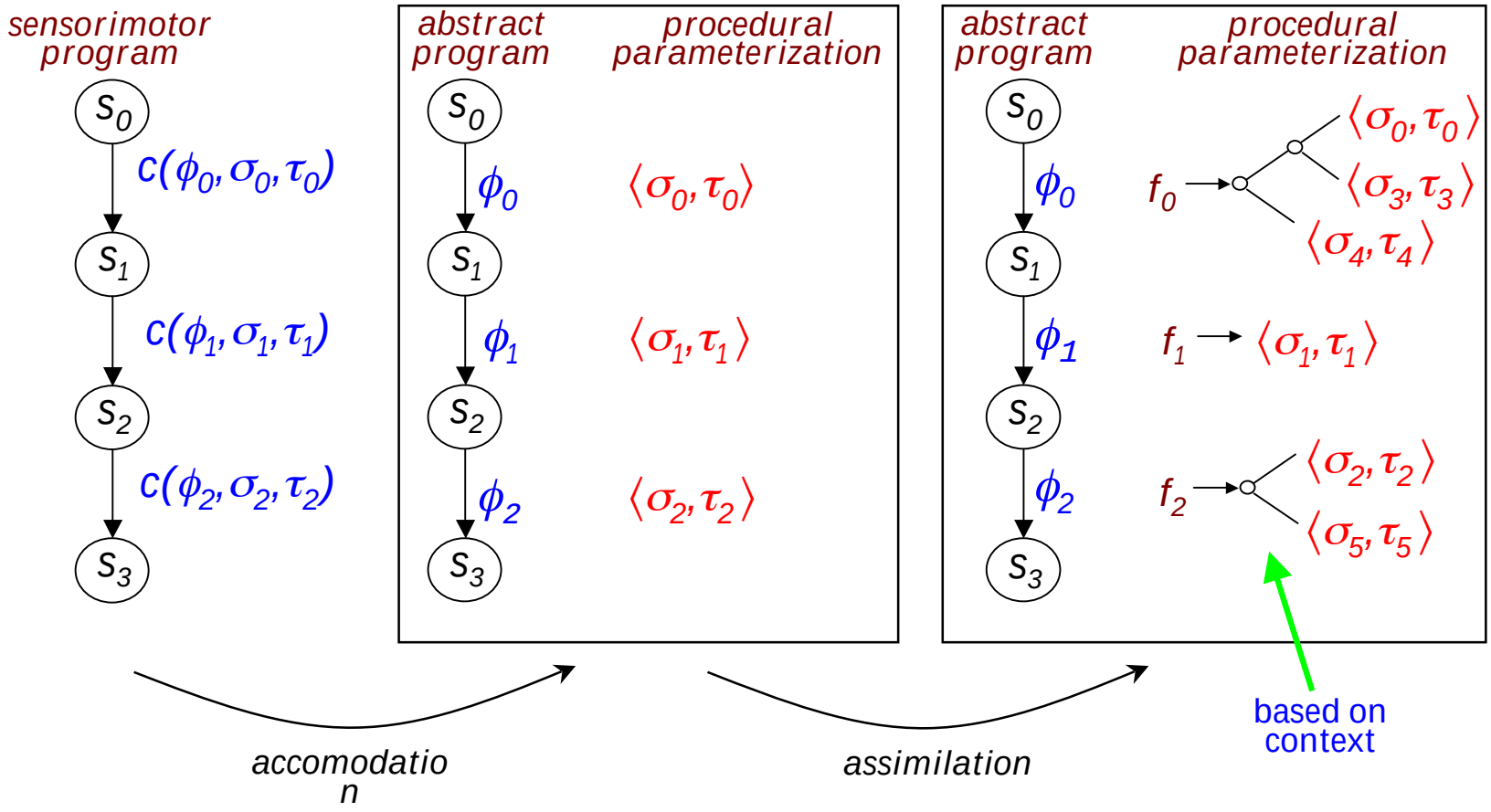
motion cue





(Hart, Sen, & Grupen – EpiRob '08)

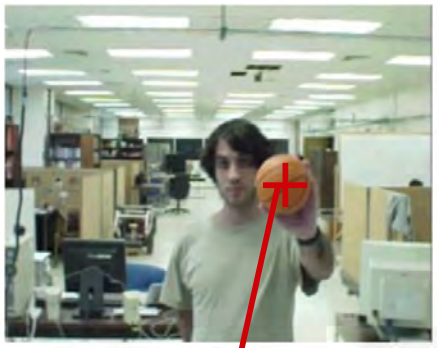
Cognitive Abstraction: Schema



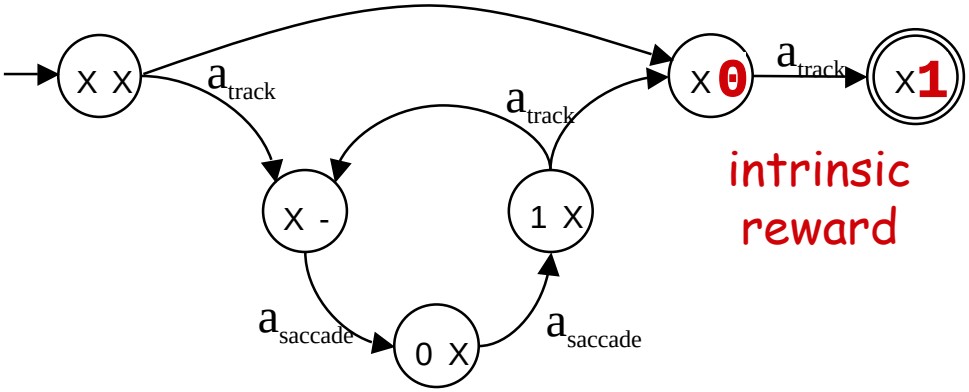
Hart, Sen, & Grupen - EpiRob 2008

Generalization of Signal Level SEARCHTRACK

training context - 25 trials



saturation cue



intrinsic reward

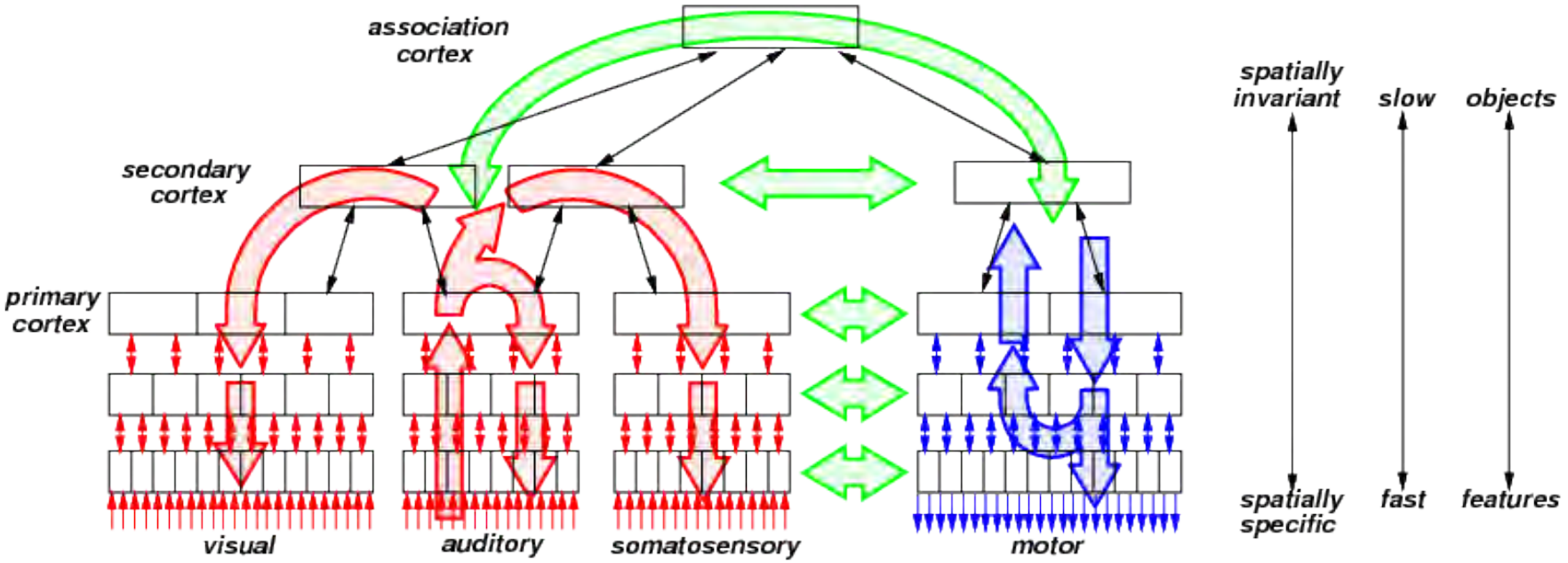
Proposition #3: Cognitive Representation

mirror neurons

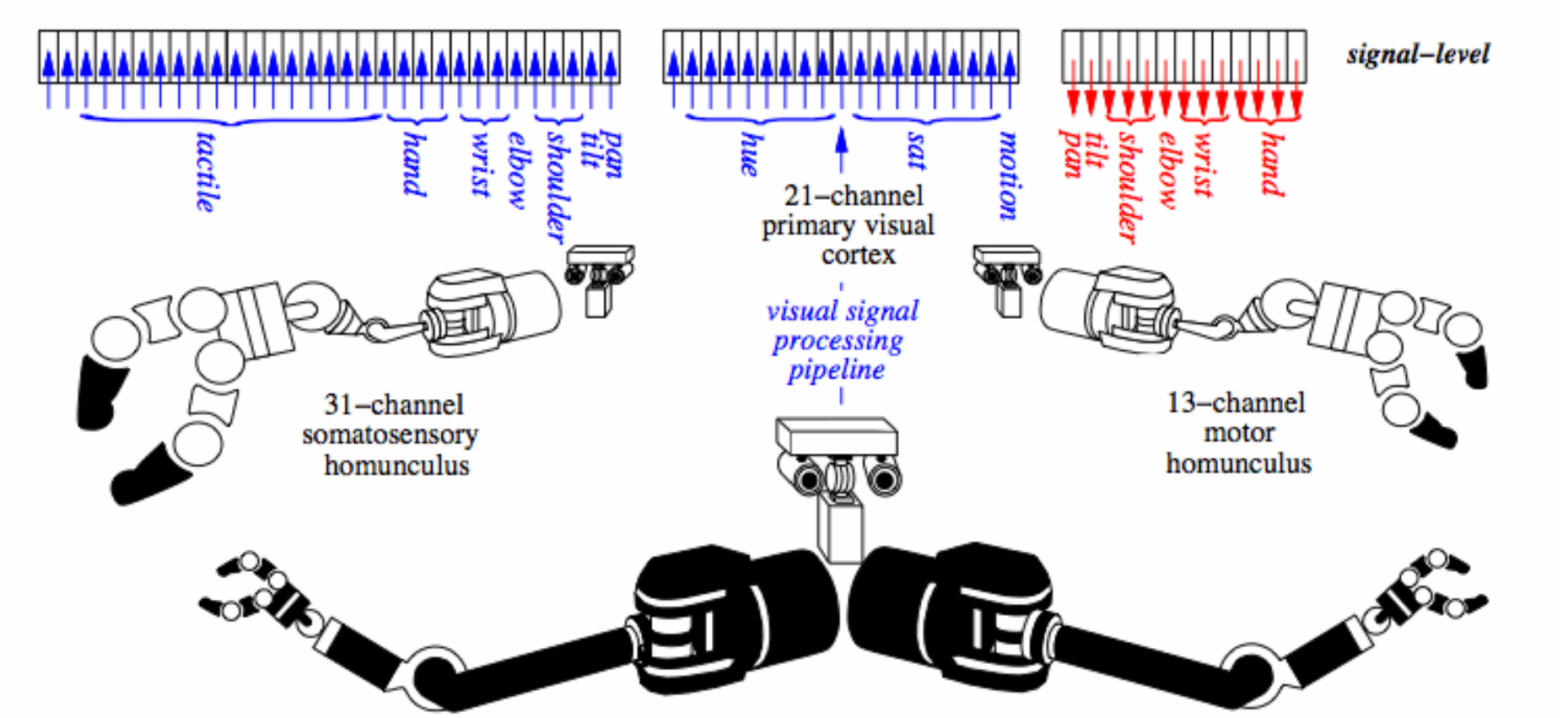
- cells (or networks of cells) that fire both when an animal acts and when it observes similar actions in others
- systems underlying perception/action coupling, imitation, and intentions
- related to Hebbian or Associative Learning frameworks
- thought to develop in the first year of life

probabilistic affordance *catalogs*

Hierarchical Cortical Control Circuits

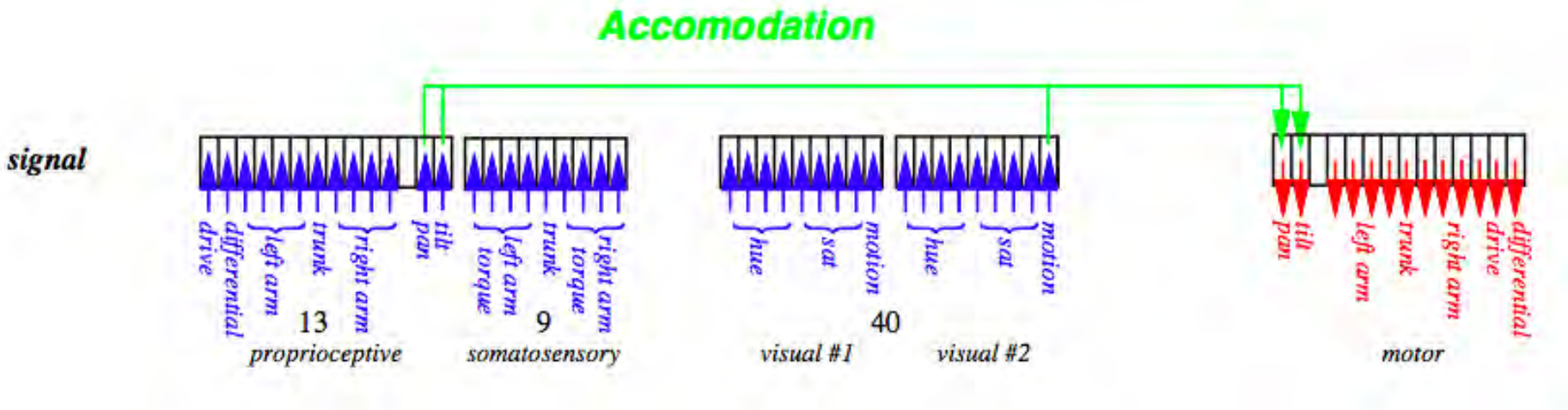


Cortical Homunculi

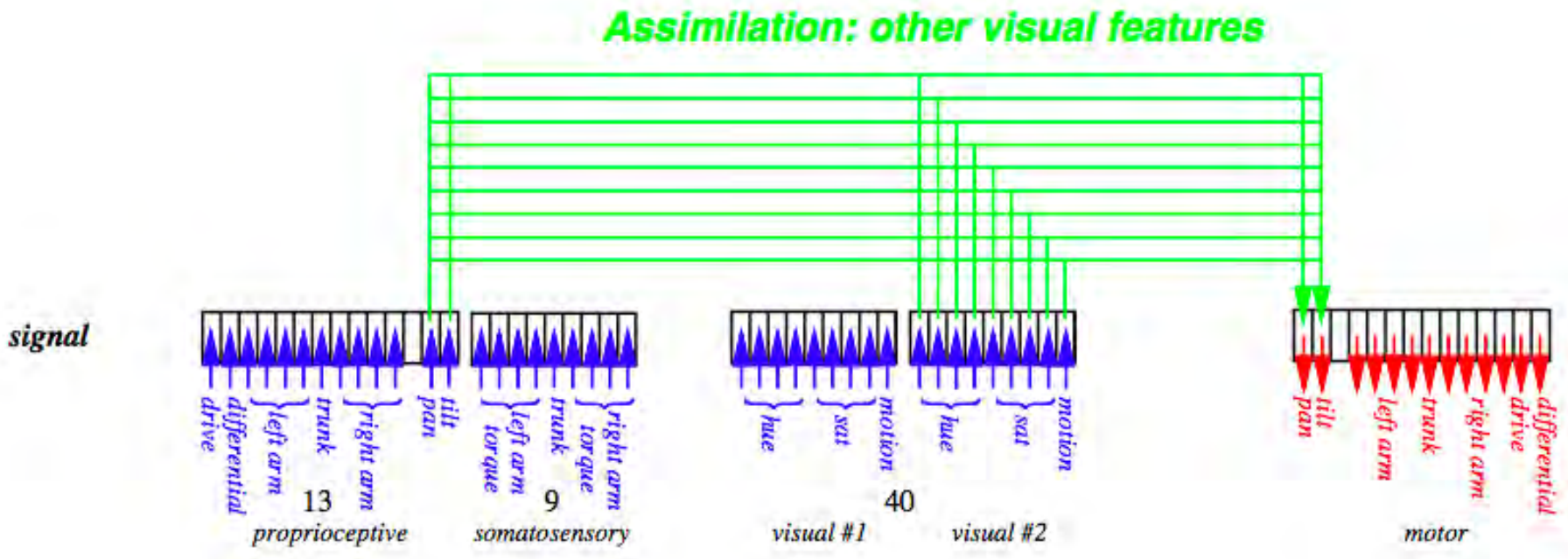


Generalization of Signal Level SEARCHTRACK

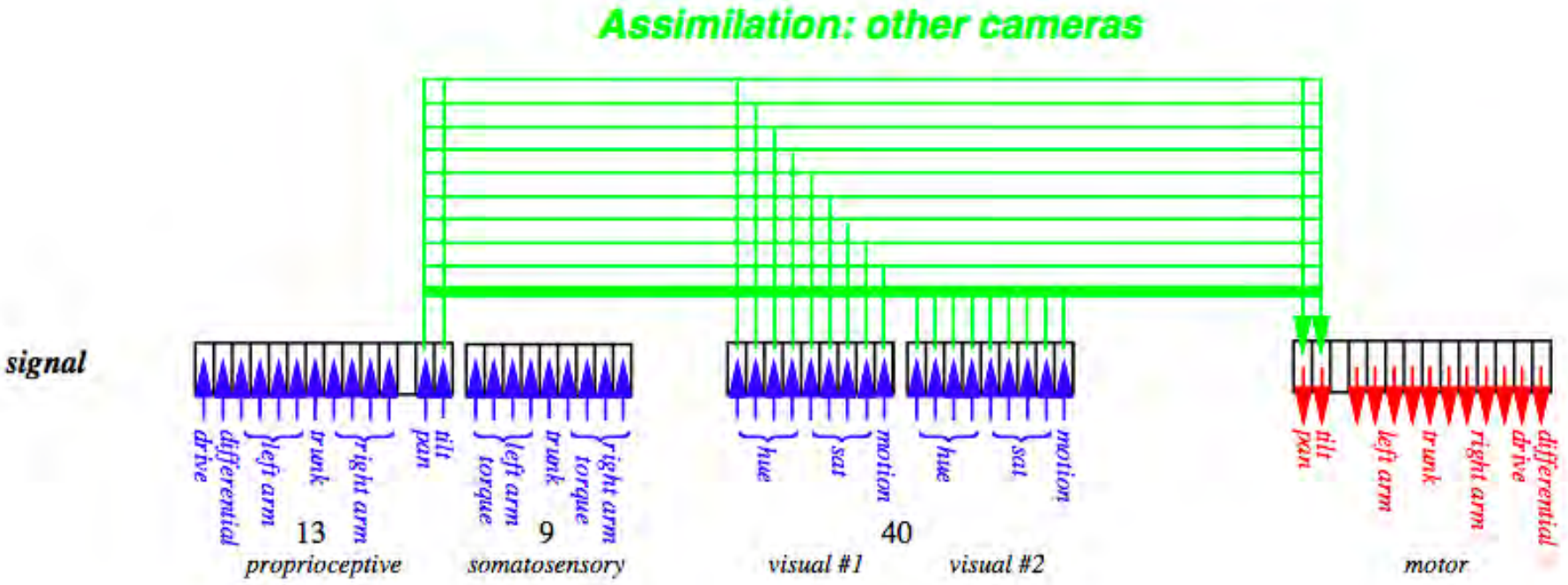
growing a cortical representation



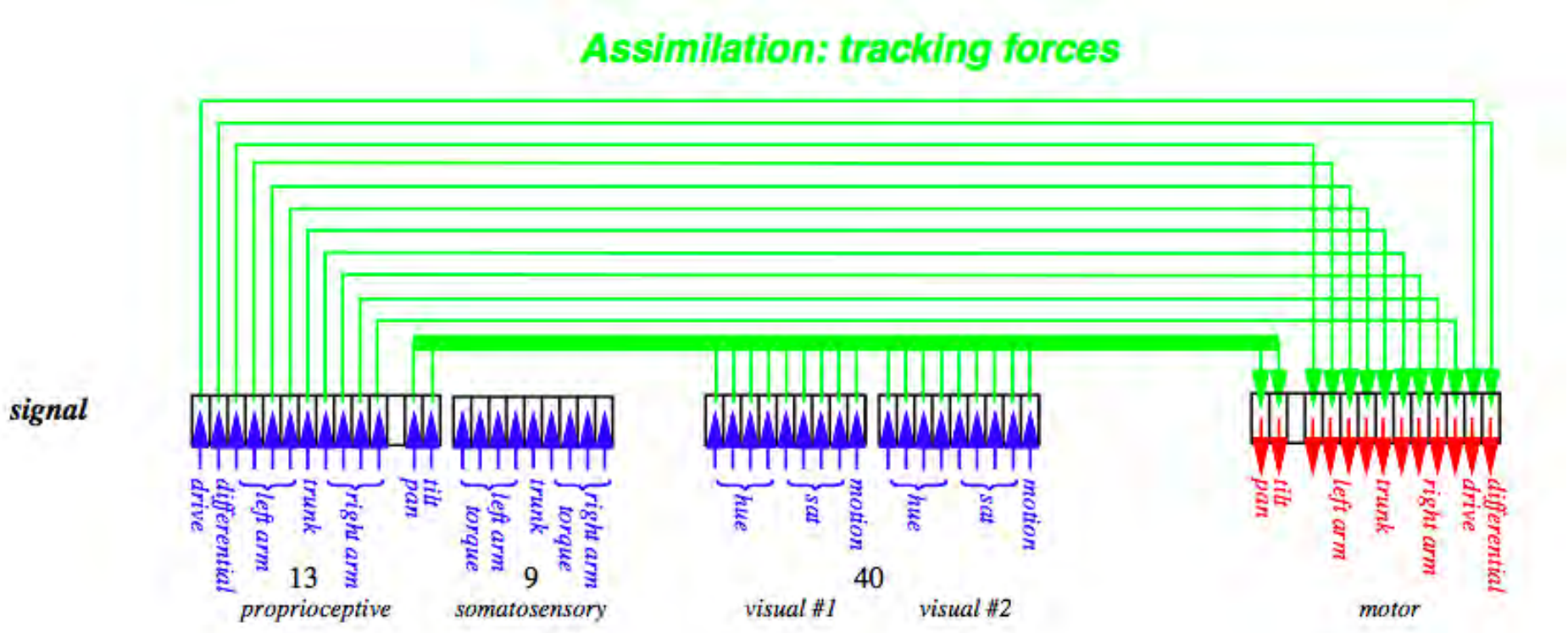
Generalization of Signal Level SEARCHTRACK



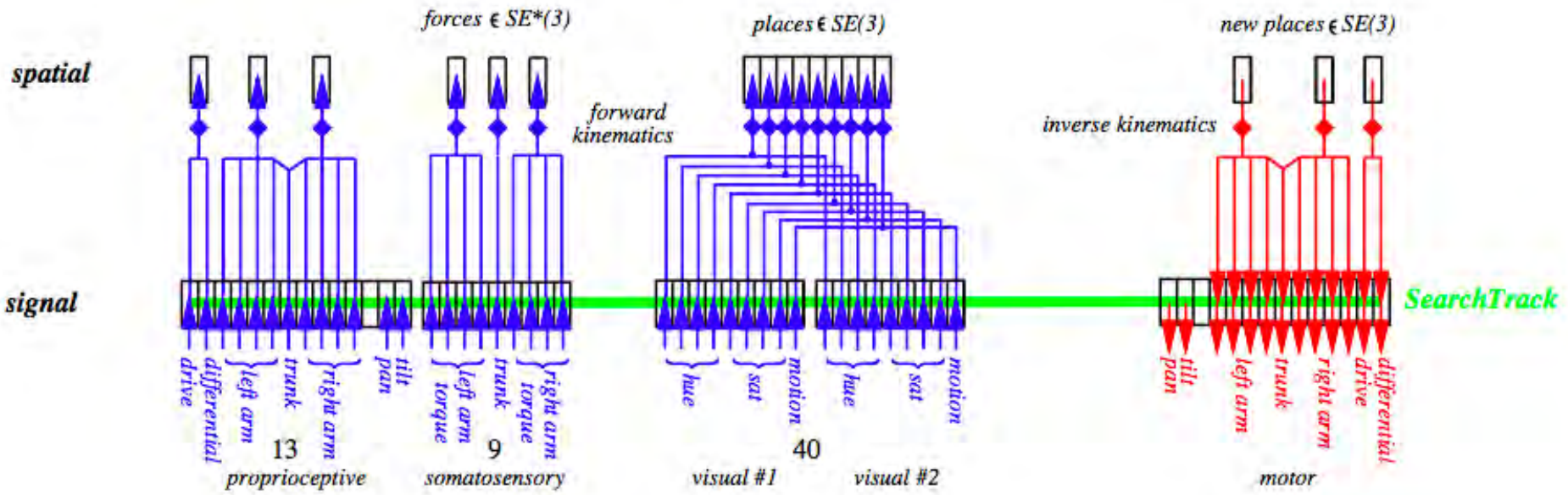
Generalization of Signal Level SEARCHTRACK



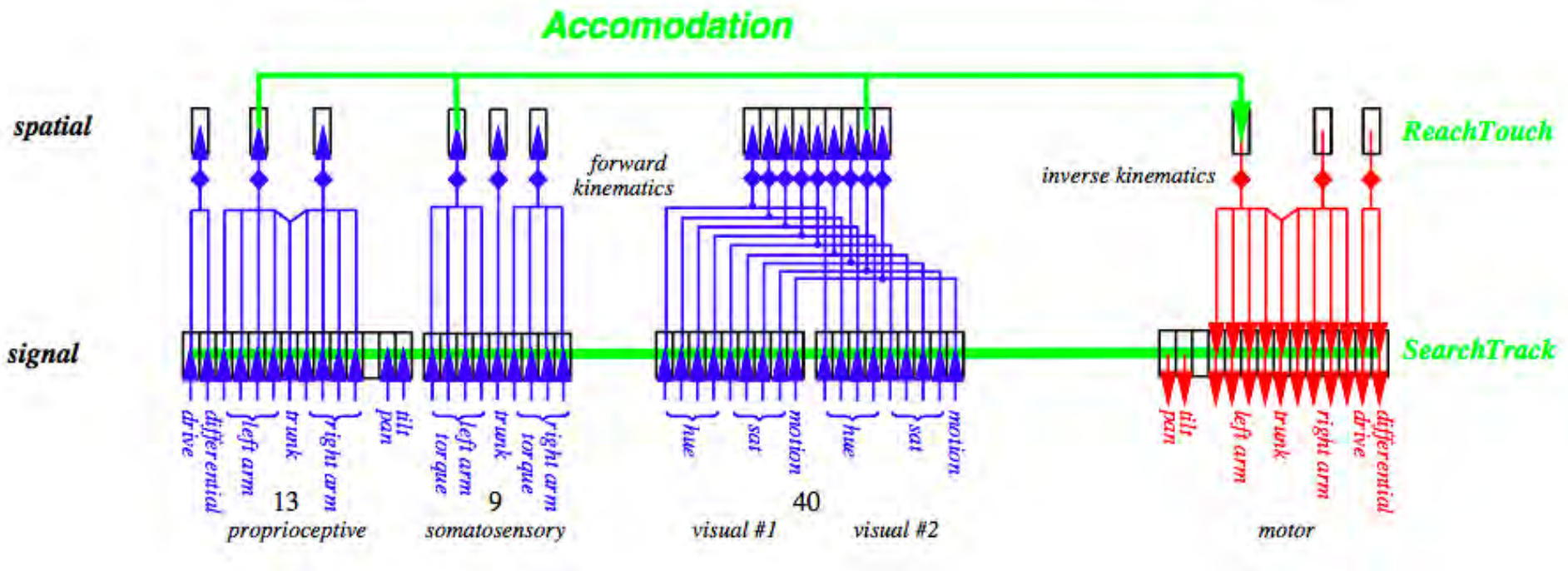
Generalization of Signal Level SEARCHTRACK



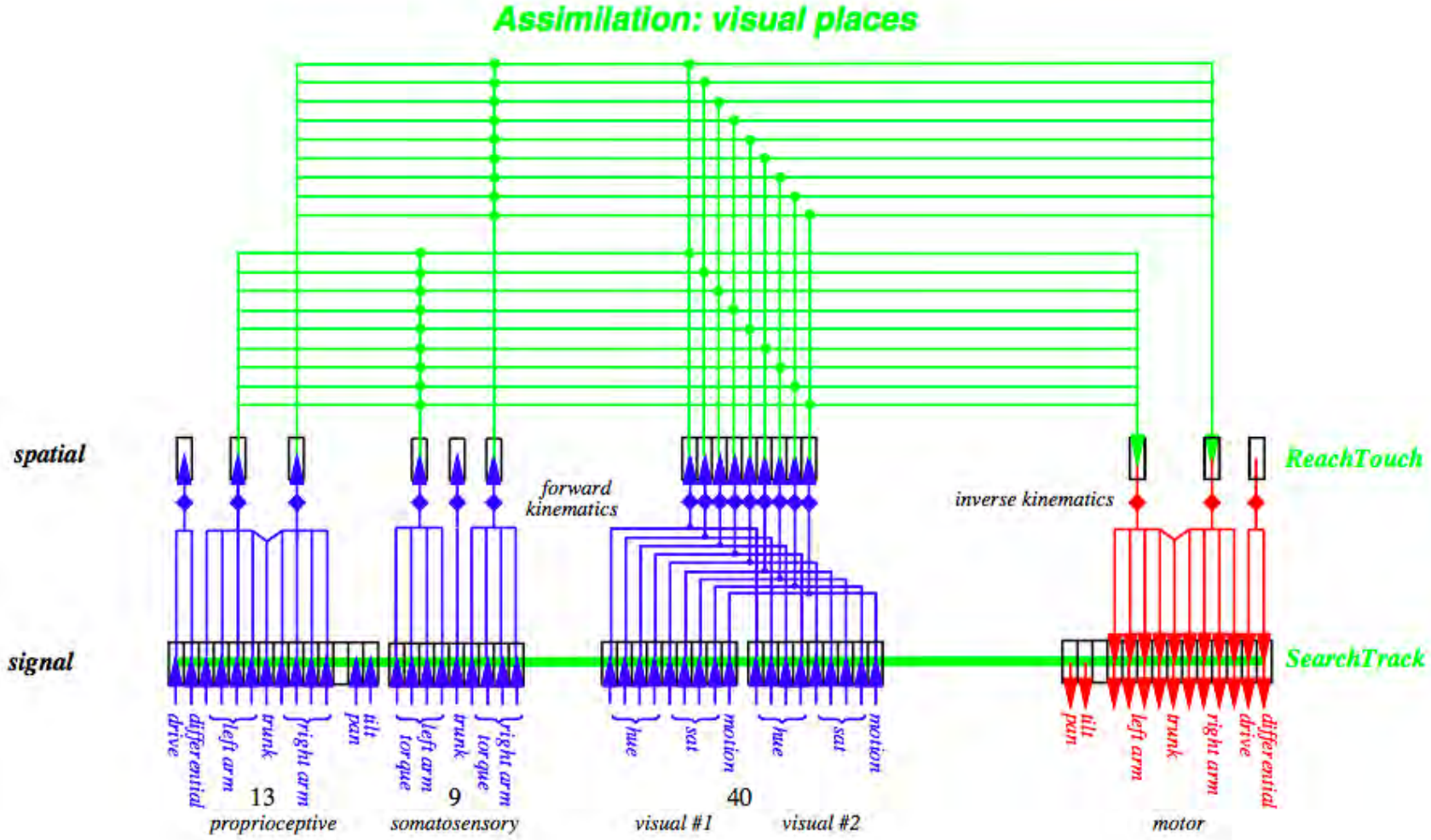
Spatial Recoding: touching what you see



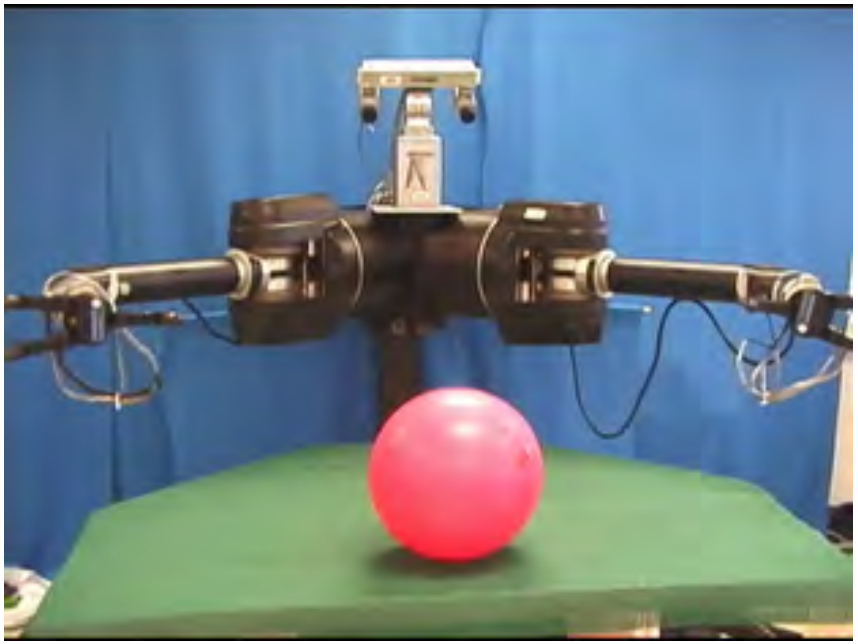
A Developmental Context: ReachTouch



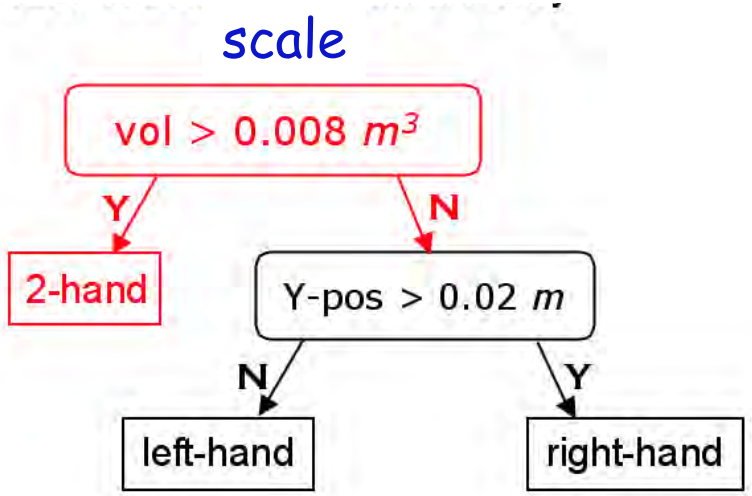
Generalization of Spatial Level: ReachTouch



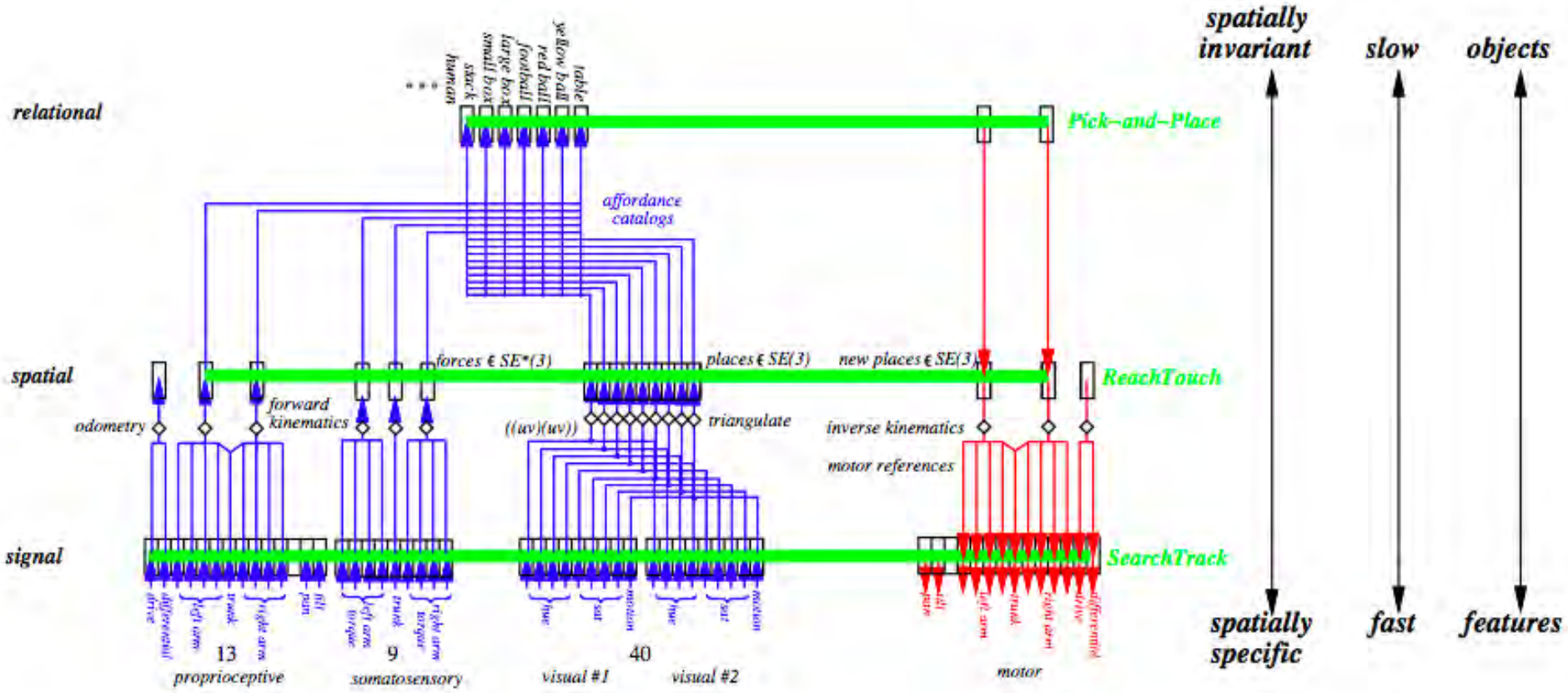
ReachTouch- handedness, scale, shape



ReachTouch procedural policy

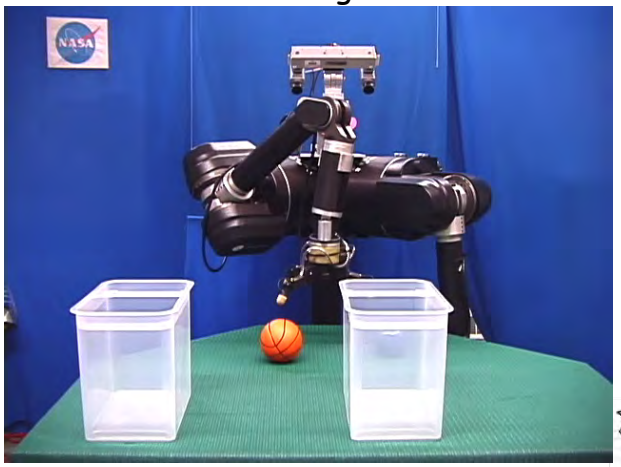


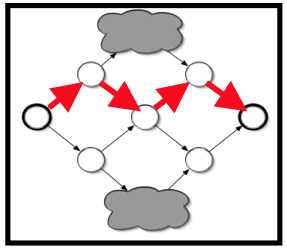
Hierarchical Cortical Control Circuits



Programming by Demonstration - conveying a *task*

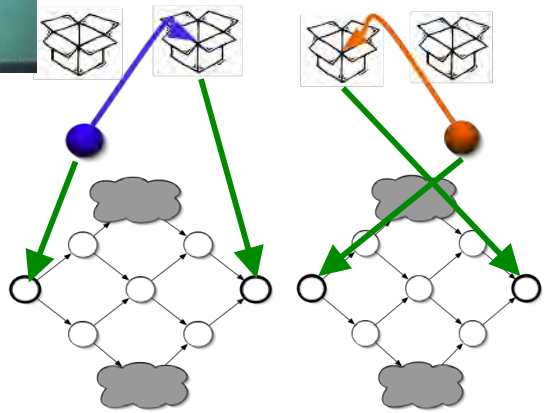
teleoperator
sorting instruction





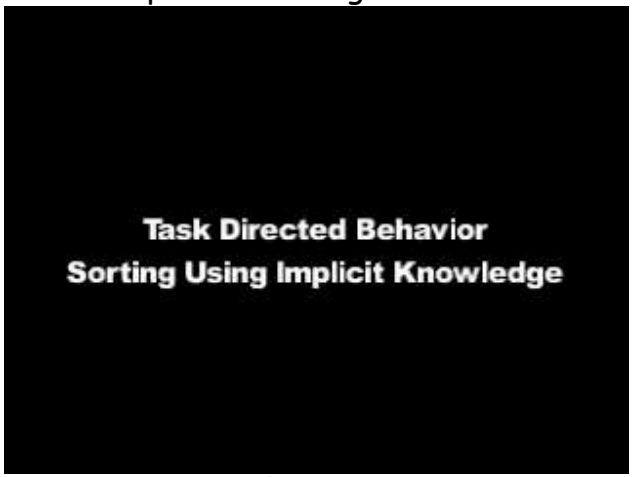
(1) parse events to find a matching schema.

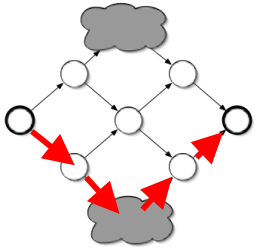
teleological stance



(2) associate goals with schema

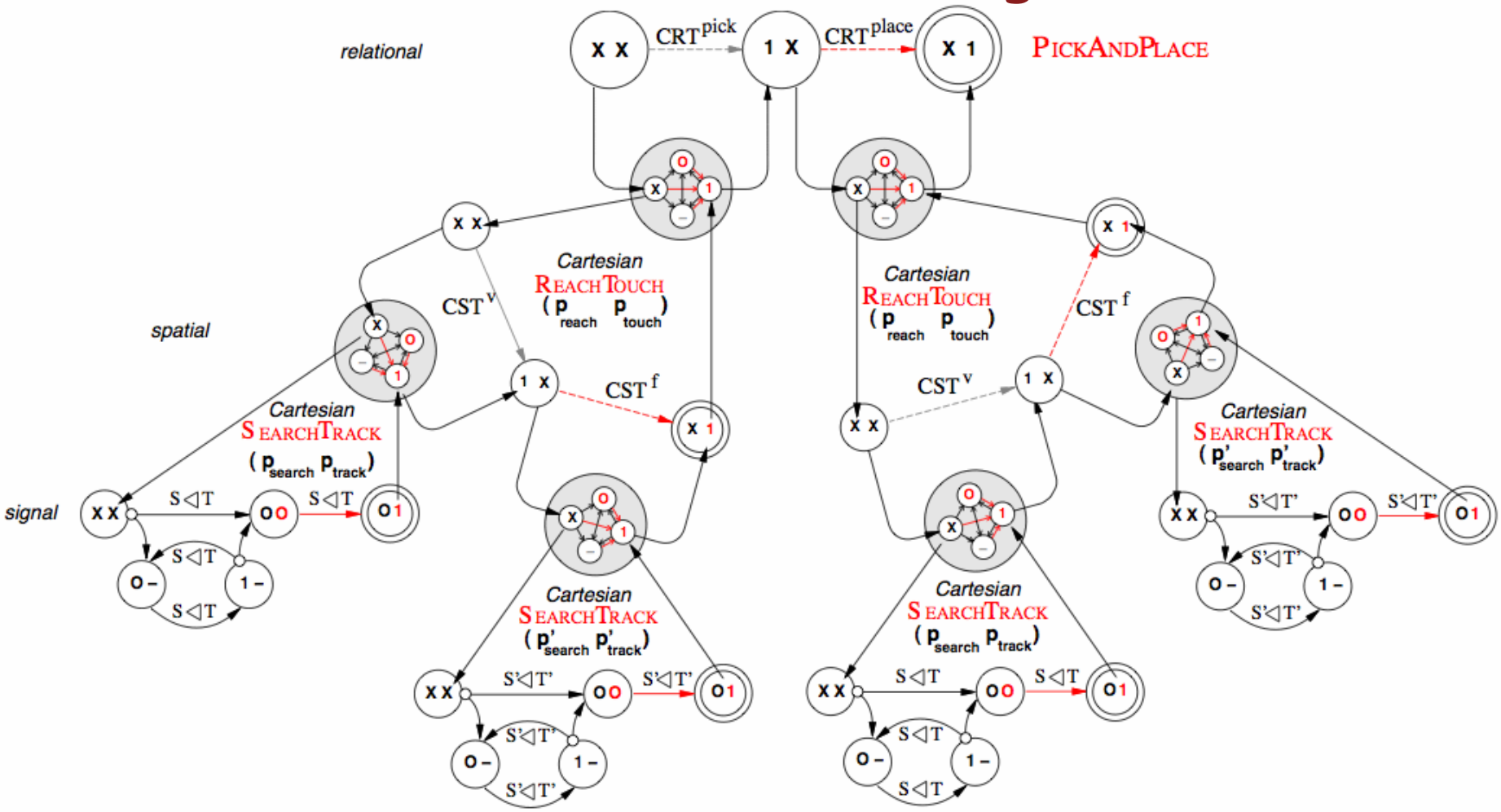
sorting replay
with prior knowledge





(3) Replicate demonstration with contingencies

Summary - Intrinsically Motivated Hierarchical Behavior and Procedural Knowledge of the World



Joint Affordance Distributions

world models: (i, j designate discrete f_σ, ϕ, τ combinations)

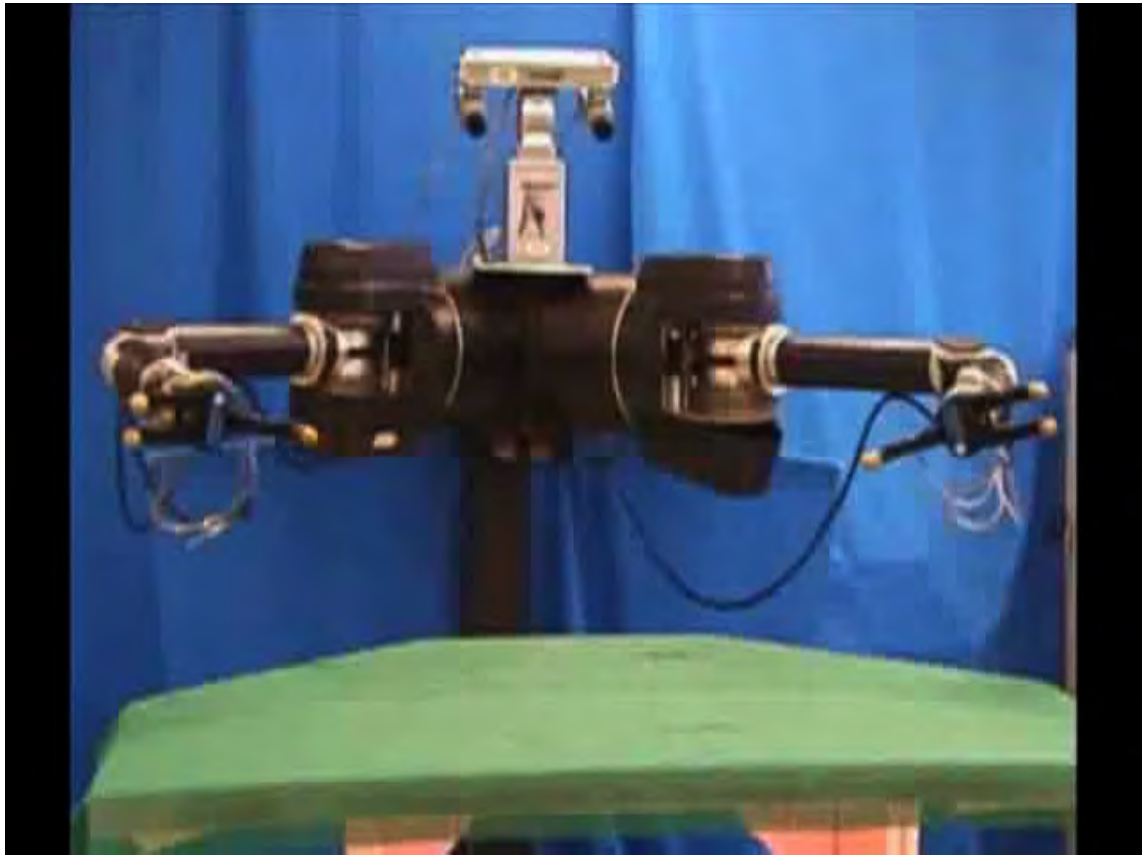
$$Pr\left(\left\{state\left(\frac{\partial\phi(f_\sigma)}{\partial u_\tau}\right)_j^{t_k},\ j \neq i\right\} \;\middle|\; \left(\frac{\partial\phi(f_\sigma)}{\partial u_\tau}\right)_i = 0\right)$$

control complexity using developmental guidance

reward

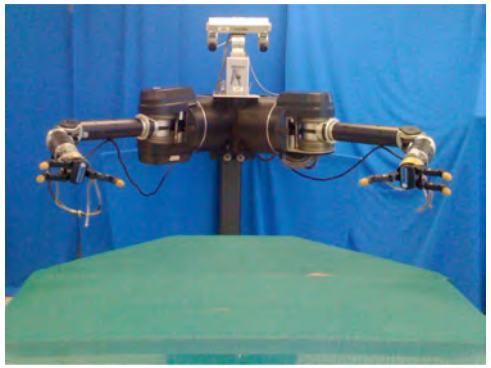
habituation: scale reward by the change in variance of this distribution

Acquiring Joint Affordances- Three *Objects*

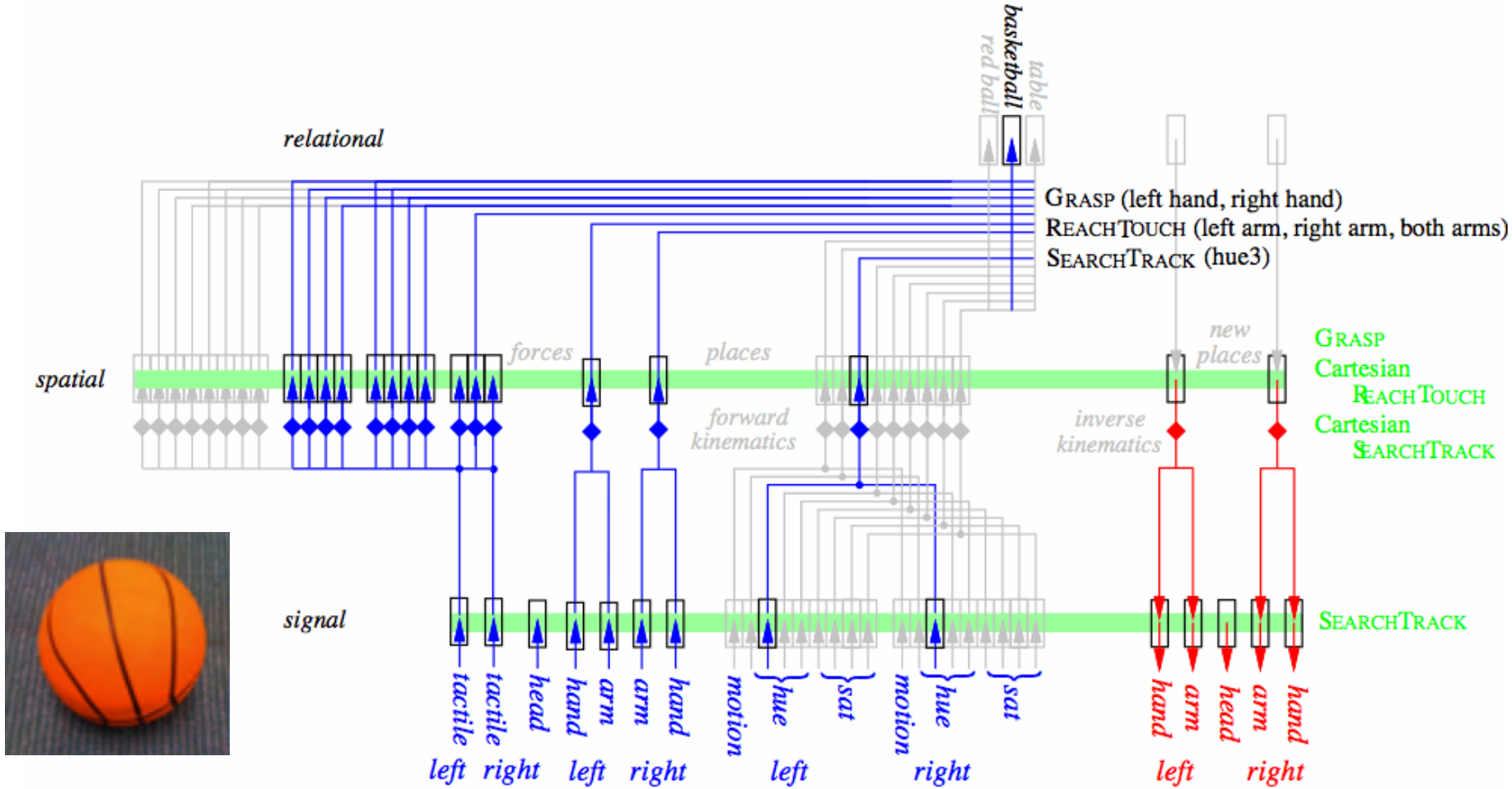


Exploration habituates when no additional information is forthcoming

Affordance *Catalogs* - Table



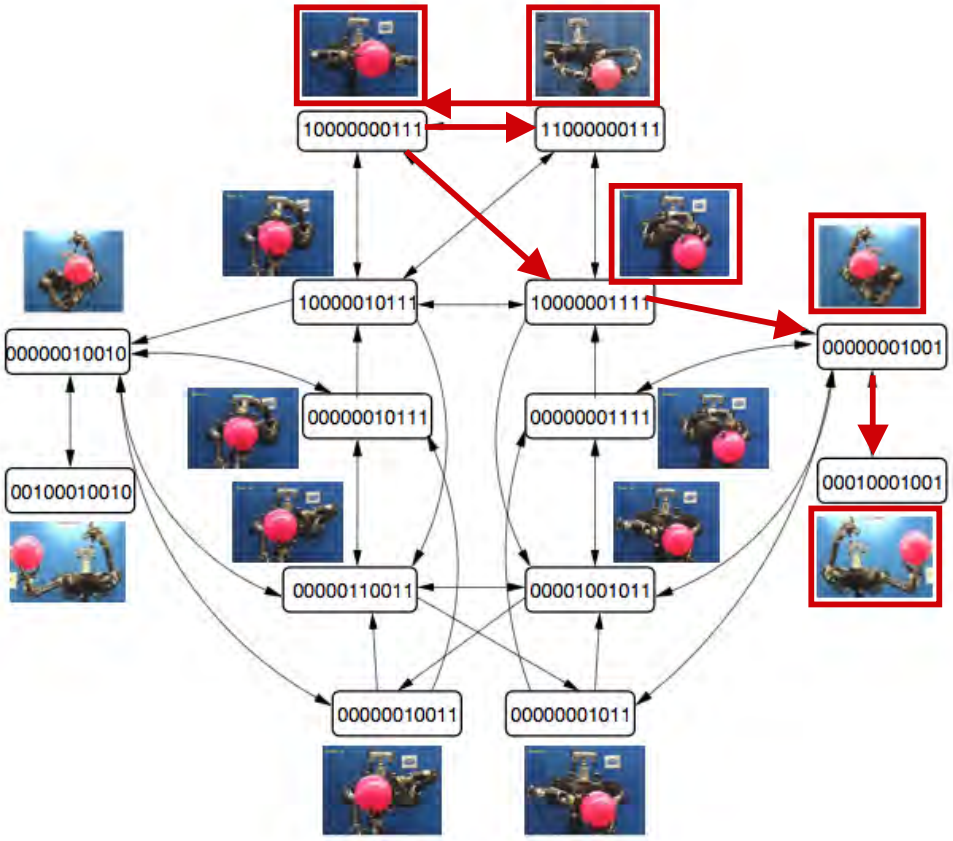
Affordance *Catalogs* - Small Basketball

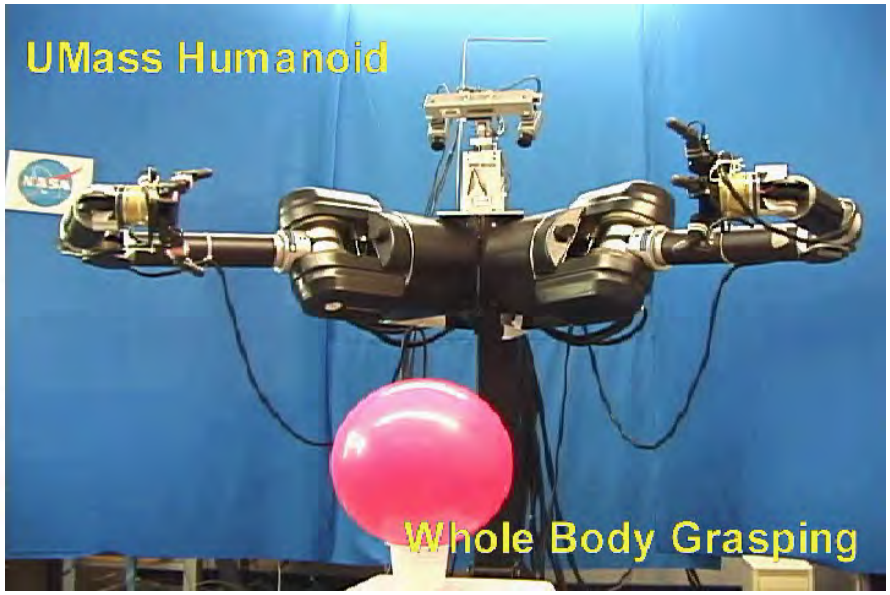


Affordance *Catalogs* - Red Ball

probabilistic affordance catalogs

Causal Invariants in the Cortex

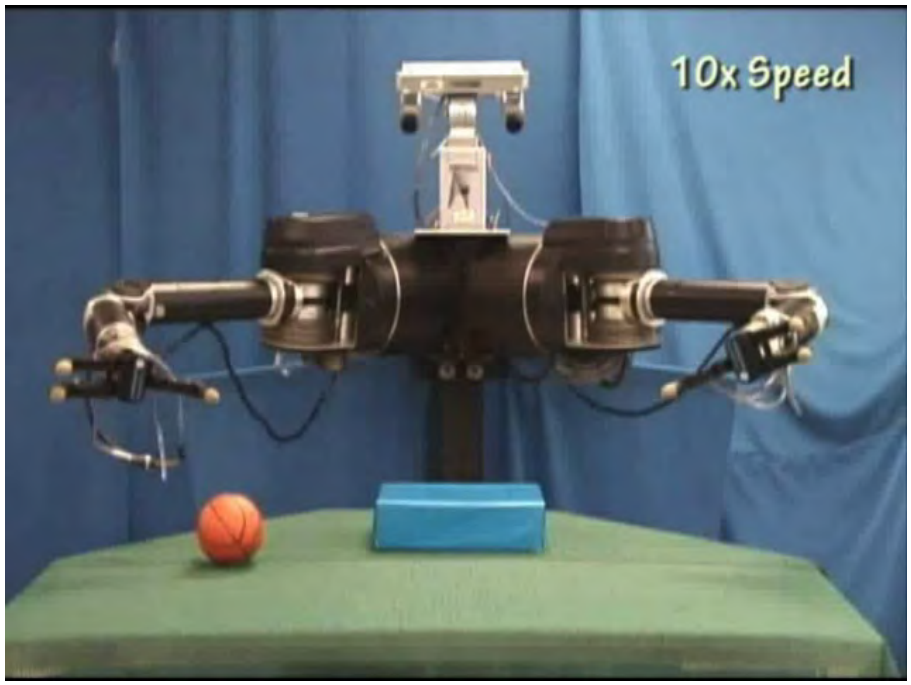


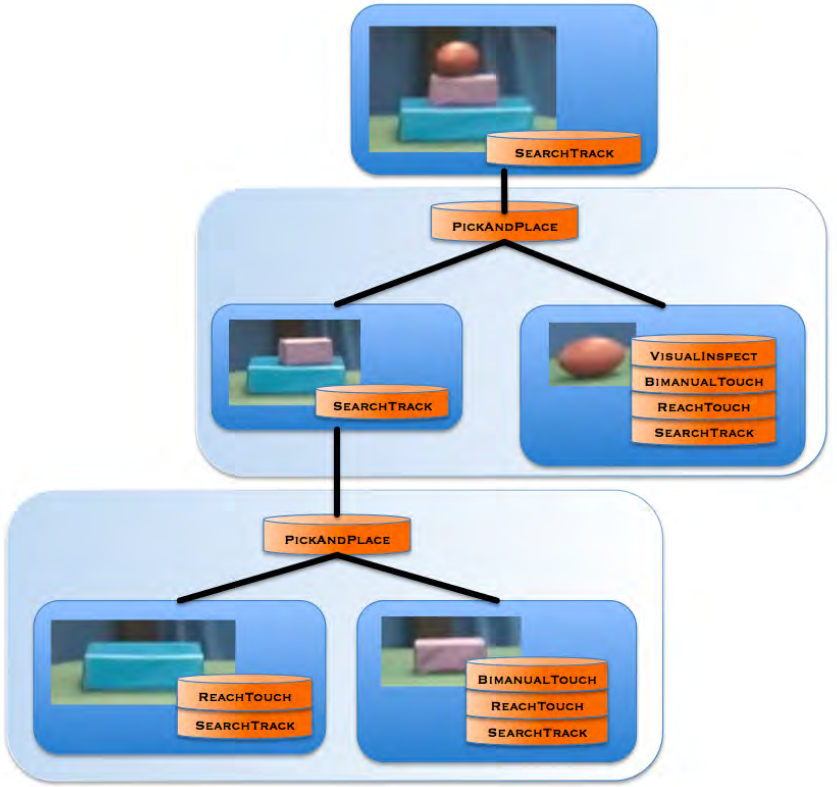


$$\phi_t \lhd \Phi_{g'}$$

…at least one stable grasp must exist at all times…

Relational Catalogs





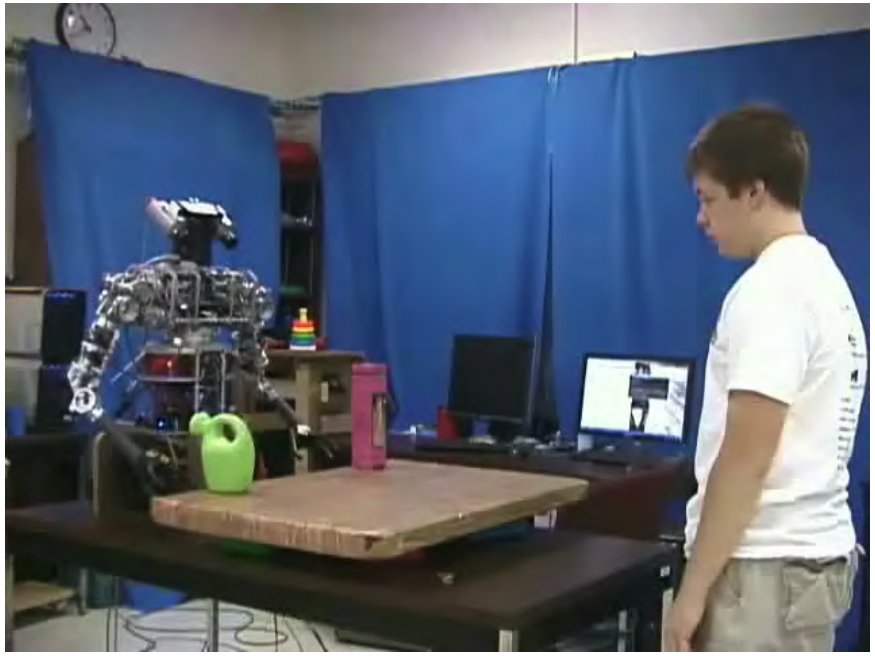
some multi-body relations afford stable stacks
stable stacks provide opportunities to discover rewarding stack affordances (trackable, touchable, graspable, etc.)

The Future - Expressive Communicative Actions

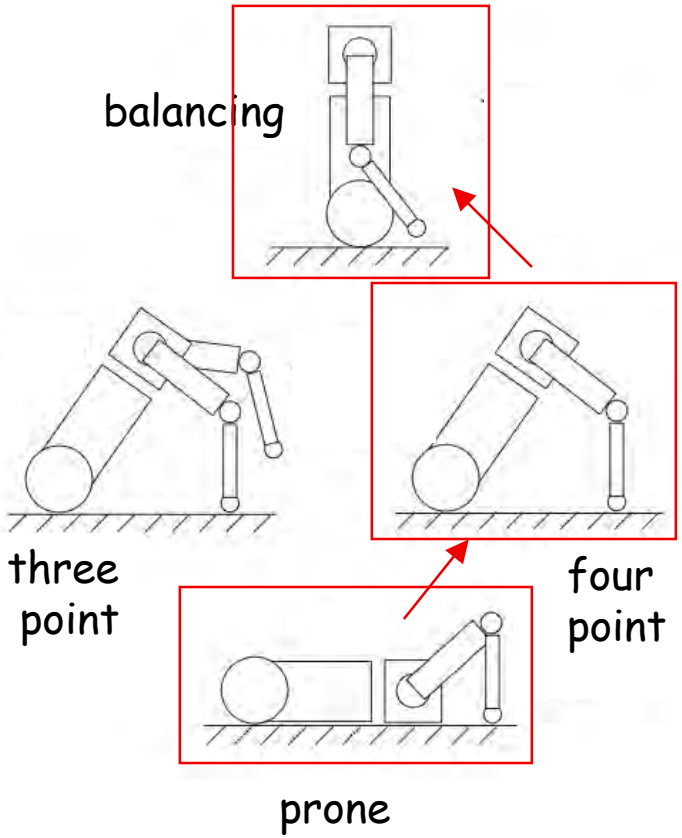
learning about kinodynamic and intentional agents

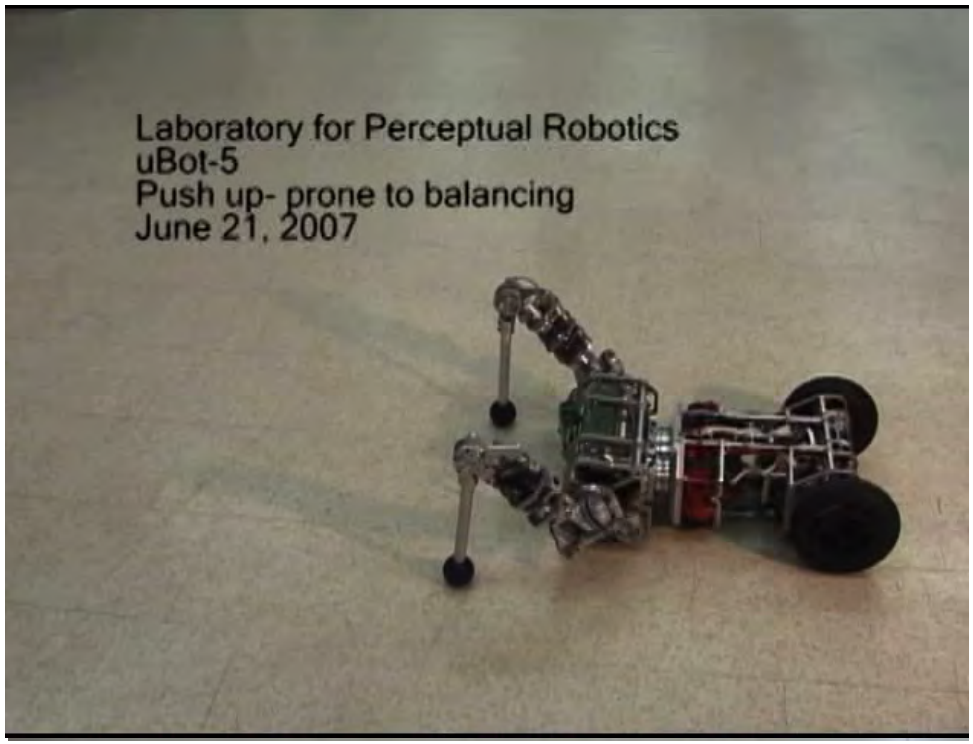
expressive

receptive



The Future - Combining Affordances for Dexterous Mobility and Manipulation





affordances of postural stability and terrain type

The Future

Science: the human brain is among the most complex systems ever studied.

- animal, viral, and bacterial "models" are commonly used to study processes that are thought to be much more universal than the simple forms that we study.

…a robotic model system for the human *mind*…

- an expanding information theoretic dimension to neuroscientific research

robots can help us understand perception, learning and development, cognitive representation, and intelligence

Technological Artifacts:
personal robotics, telemedicine---autism spectrum disorders, eldercare, PTSD, therapeutic rehabilitation, physical and cognitive prosthetics

Acknowledgements

Past Students

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Justus Piater (Université de Liège)
Rob Platt (NASA-JSC, MIT)
Srinvas Ravela (MIT)
Mike Rosenstein (iRobot)
John Sweeney (FDO Partners)
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Current Students

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Grant Sherrick
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