NEW YORK UNIVERSITY

The Future of AI
+
Odds and Ends

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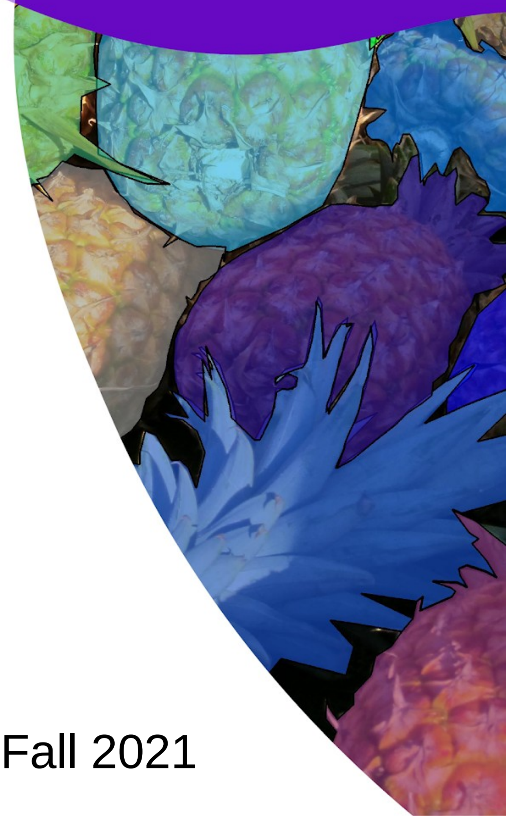


Deep Learning, NYU, Fall 2021

FACEBOOK AI

Backprop as Lagrangian Optimization

Optimization under constraints

Reformulating Deep Learning

- **Loss**

$$L(x,y,w) = C(z_K, y) \;\; \text{such that } z_{k+1} = g_k(z_k, w_k), \quad z_0 = x$$

- **Lagrangian for optimization under constraints**

$$L(x,y,z,\lambda,w) = C(z_K, y) + \sum_{k=0}^{K-1} \lambda_k^T (z_{k+1} - g_k(z_k, w_k))$$

- **Optimality conditions:**

$$\frac{\partial L(x,y,z,\lambda,w)}{\partial z_k} = 0, \quad \frac{\partial L(x,y,z,\lambda,w)}{\partial \lambda_k} = 0, \quad \frac{\partial L(x,y,z,\lambda,w)}{\partial w_k} = 0$$

Reformulating Deep Learning

$$\frac{\partial L(x,y,z,\lambda,w)}{\partial \lambda_k} = z_{k+1} - g_k(z_k, w_k) = 0 \Longrightarrow z_{k+1} = g_k(z_k, w_k)$$

$$\frac{\partial L(x,y,z,\lambda,w)}{\partial z_k} = \lambda_{k-1}^T - \lambda_k^T \frac{\partial g_{k-1}(z_{k-1}, w_{k-1})}{\partial z_k} = 0 \Longrightarrow$$

- **Backprop!**
  - Lambda is the gradient

$$\lambda_{k-1} = \frac{\partial g_{k-1}(z_{k-1}, w_{k-1})}{\partial z_k}^T \lambda_k$$

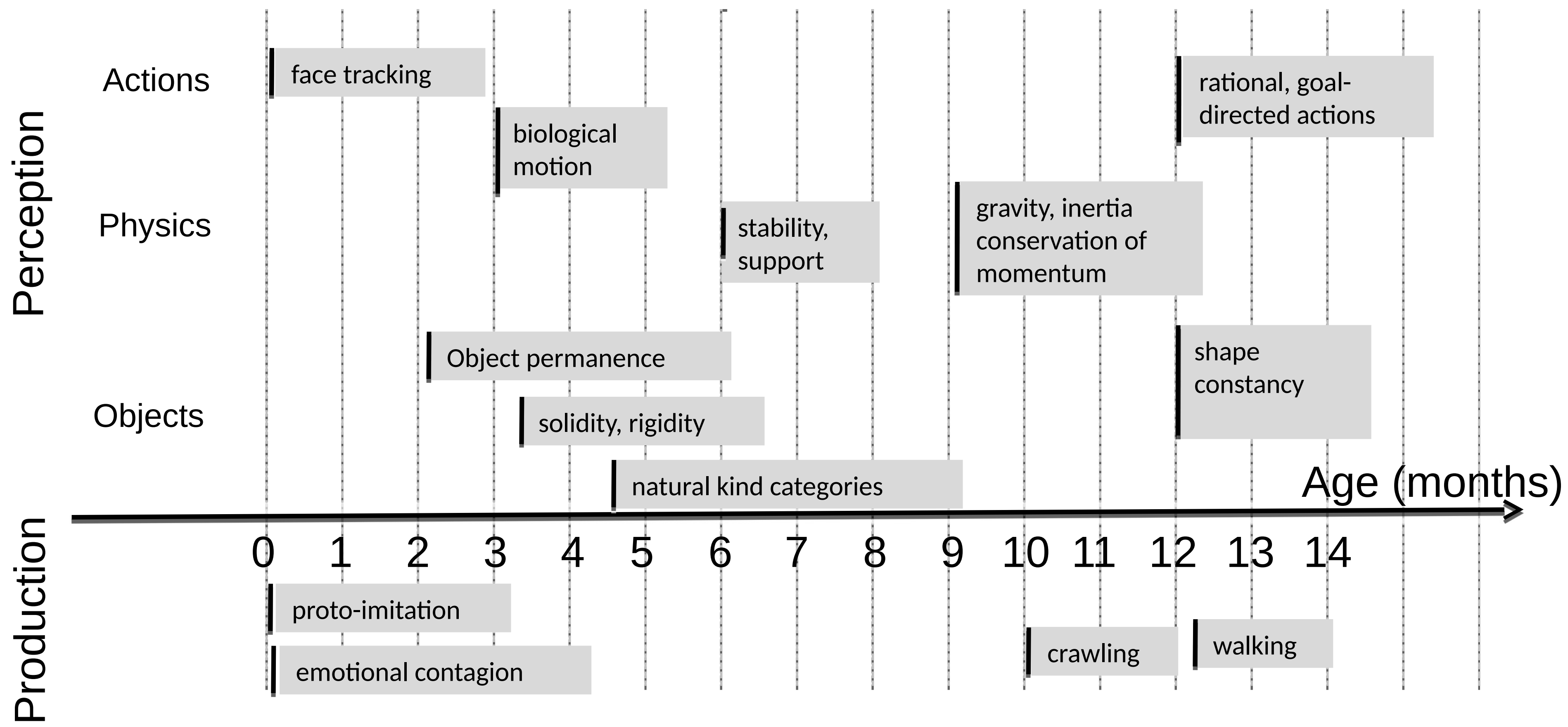
$$\frac{\partial L(x,y,z,\lambda,w)}{\partial w_k} = \lambda_{k+1}^T \frac{\partial g_k(z_k, w_k)}{\partial w_k}$$

FACEBOOK AI

How do humans and animals learn so quickly?

Not supervised.
Not Reinforced.

When infants learn models of the world [after Emmanuel Dupoux]

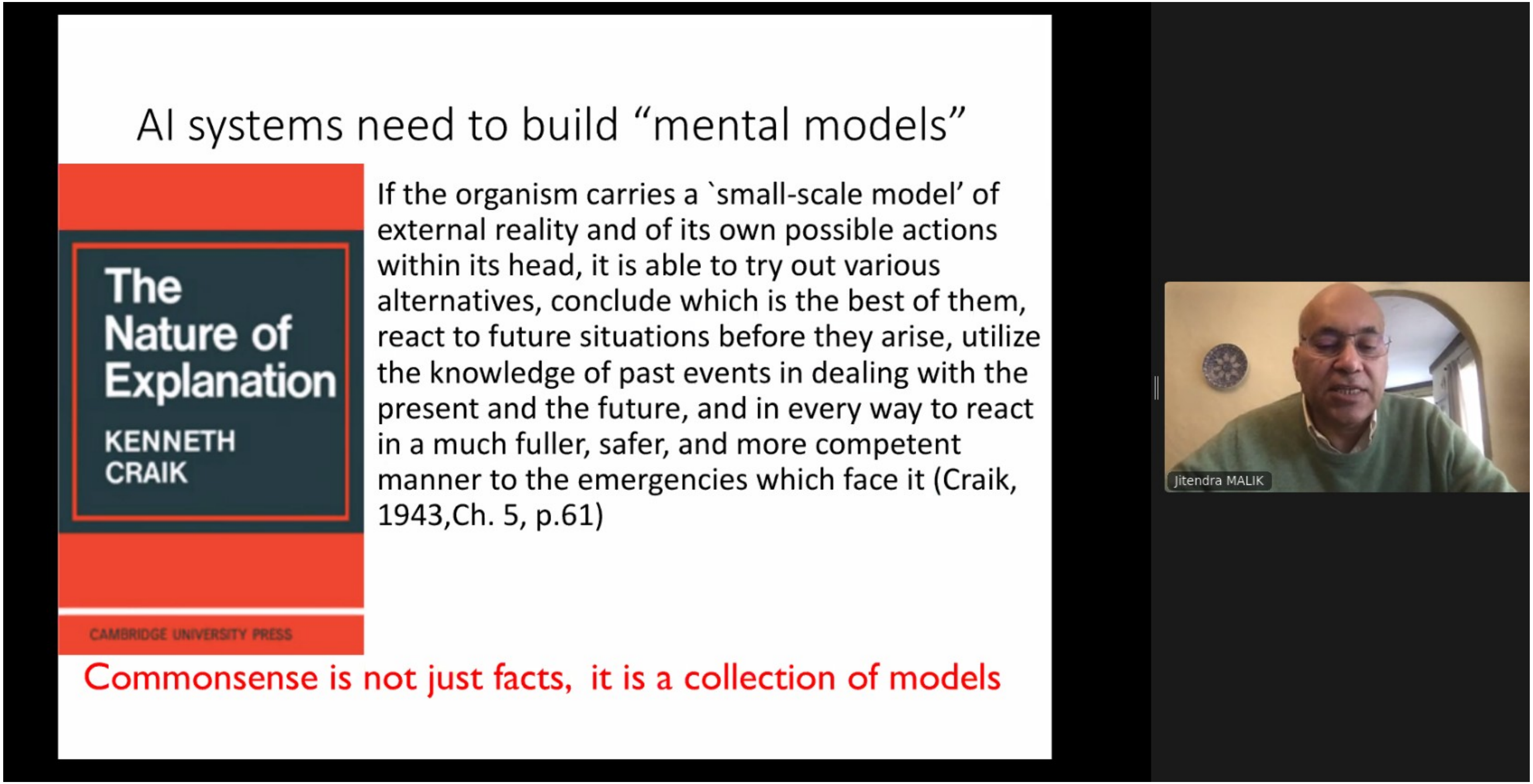


How do Human and Animal Babies Learn?

- **How do they learn how the world works?**
- **Largely by observation, with remarkably little interaction (initially).**
- **They accumulate enormous amounts of background knowledge**
  - About the structure of the world, like intuitive physics.
- **Perhaps common sense emerges from this knowledge?**

Photos courtesy of Emmanuel Dupoux

From Jitendra Malik's talk



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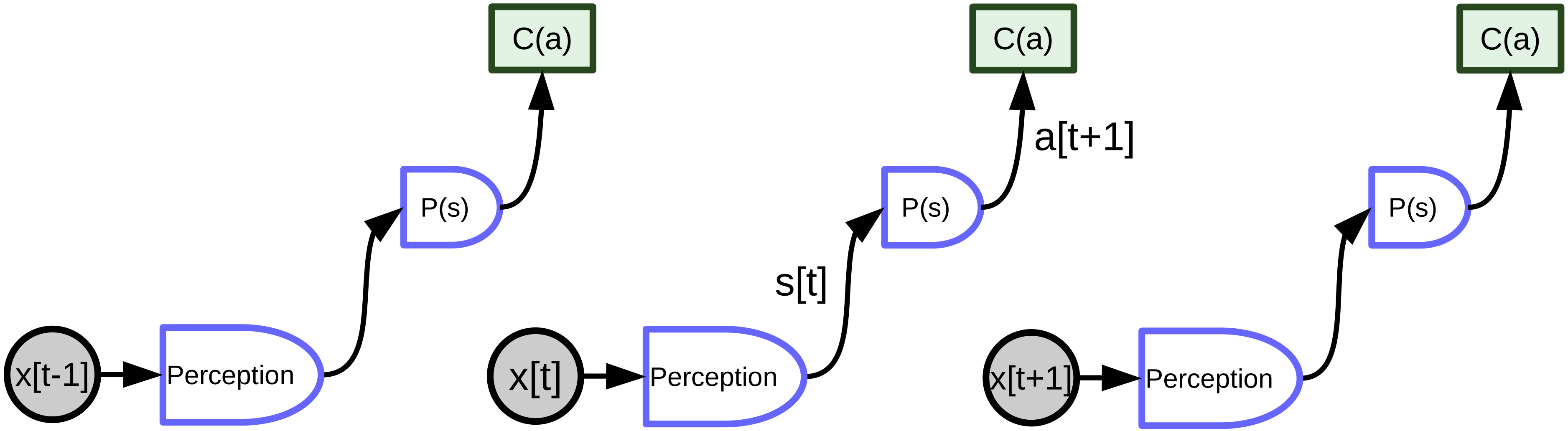
DL & Control

Learning predictive forward models

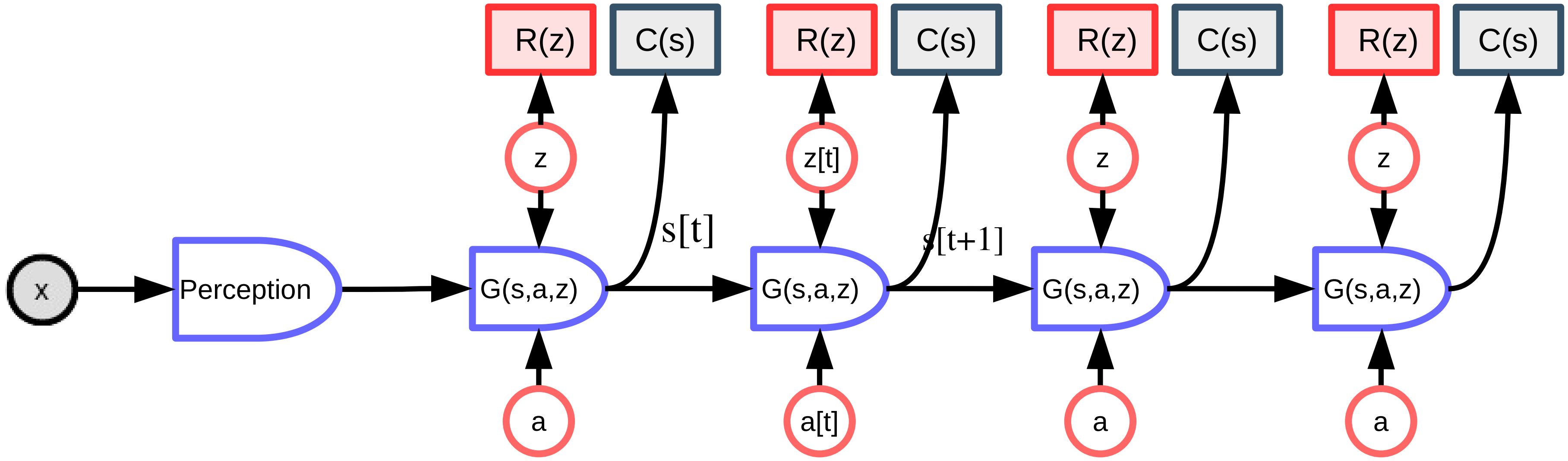
Model-free RL: C(s,a) is the world (not differentiable)

- **Cost/Energy: C(a[t]) is the real world: not differentiable**
- **Policy: a[t] = P(s[t])**



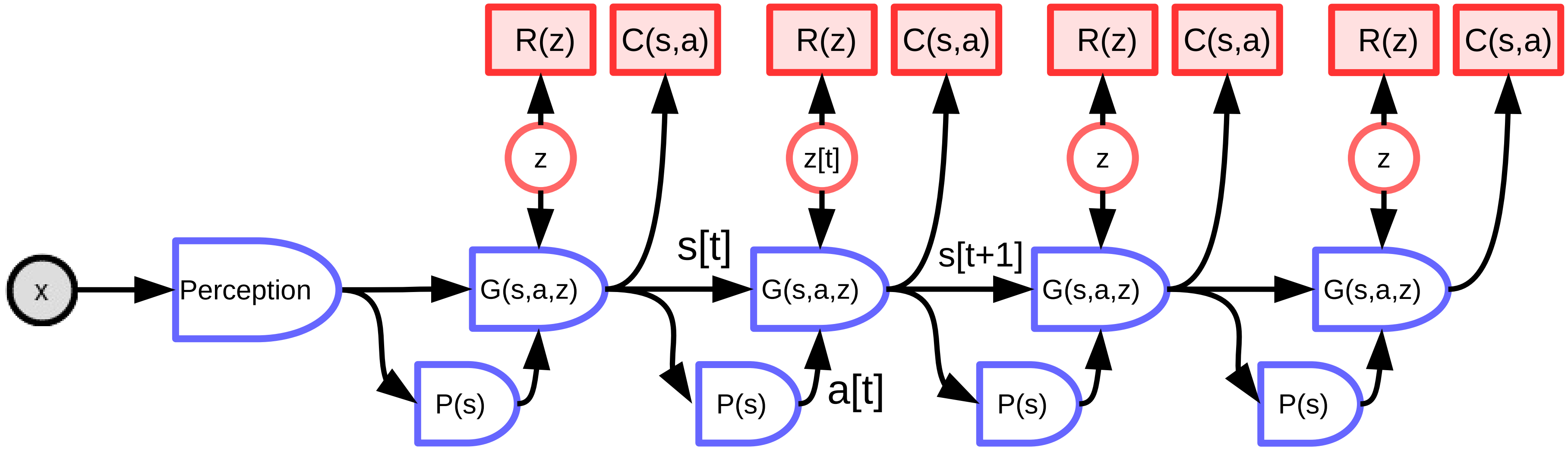
Model-Based RL: C(s) is the non-differentiable world

- **Forward model: s[t+1] = G(s[t], a[t], z[t])**
- **Latent variable z sampled from q(z) proportional to exp(-R(z))**
- **Optimize (a[1],a[2]…,a[T]) = argmin Σ_t C(s[t])**
  through backprop (== Kelley-Bryson adjoint state method)



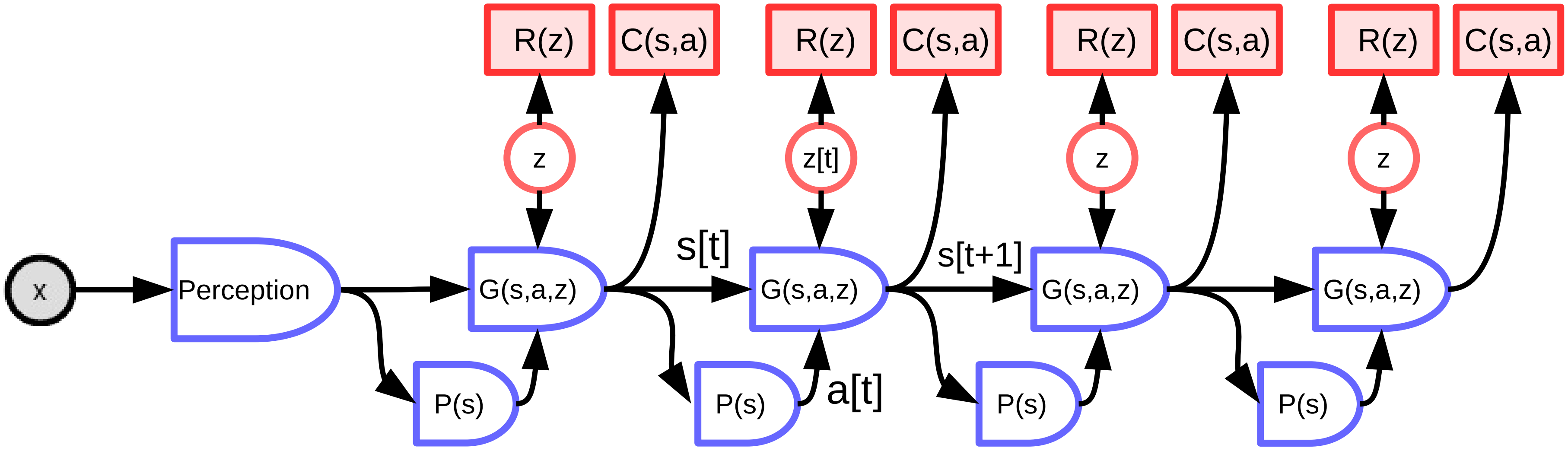
Model-Based RL

- **Forward model: s[t+1] = G(s[t], a[t], z[t])**
- **Cost/Energy: f[t] = C(s[t],a[t])**
- **Latent variable z sampled from q(z) proportional to exp(-R(z))**
- **Policy: a[t] = P(s[t])**



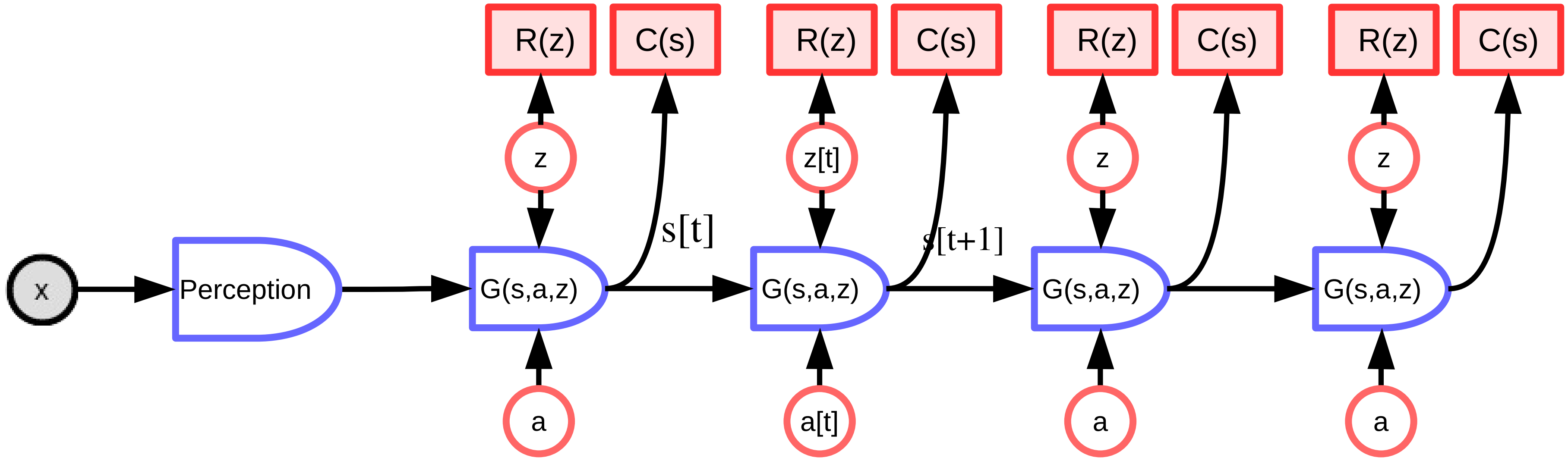
Model-Based Policy Learning with Intrinsic Objective

- **Forward model: s[t+1] = G(s[t], a[t], z[t])**
- **Cost/Energy: f[t] = C(s[t],a[t]) , differentiable!**
- **Latent variable z sampled from q(z) proportional to exp(-R(z))**
- **Policy: a[t] = P(s[t])**



Model Predictive Control

- **Forward model: s[t+1] = G(s[t], a[t], z[t])**
- **Cost/Energy: f[t] = C(s[t])**
- **Latent variable z sampled from q(z) proportional to exp(-R(z))**
- **Optimize (a[1],a[2]…,a[T]) = argmin Σ_t C(s[t])**



conclusions

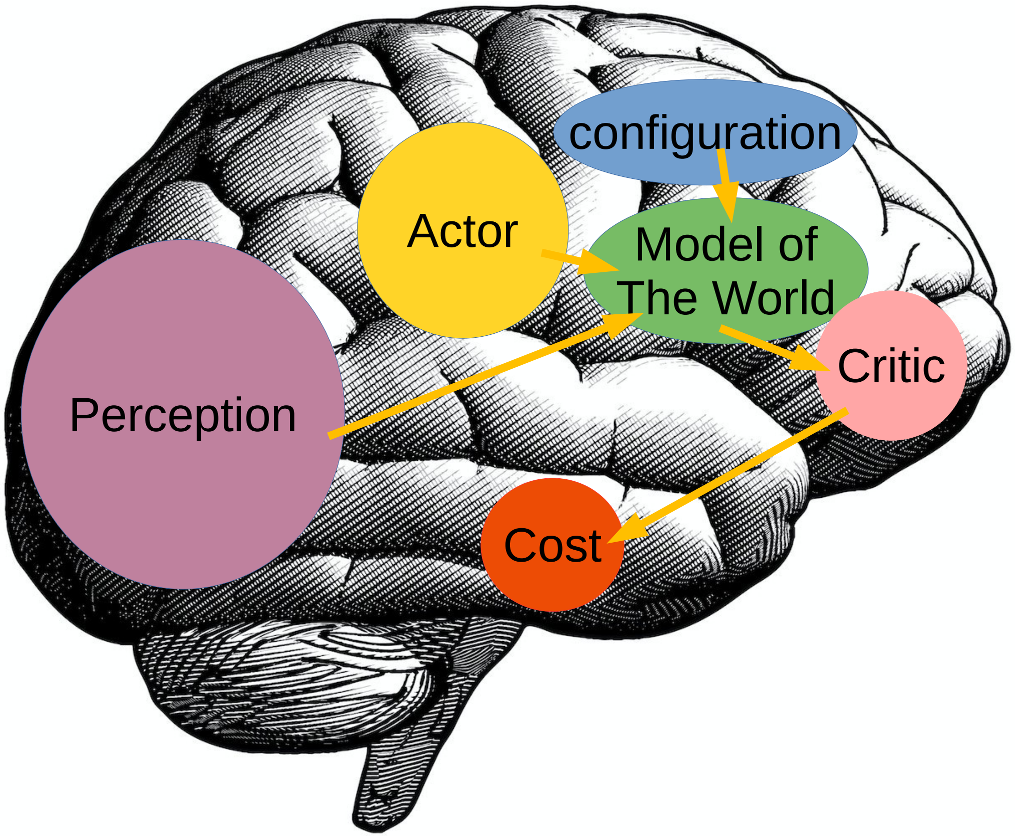
- **SSL is the future**
  - Learning hierarchical features in a task-invariant way
  - Plenty of data, **massive** networks
  - Learning Forward Models for Model-Based Control
  - Challenge: handling uncertainty in the prediction: energy-based models
- **Reasoning/planning through energy minimization**
  - Energy-Based Models with latent variables
  - Replace symbols by vectors and logic by continuous functions.
- **Learning hierarchical representations of action plans**
  - No idea how to do that!
- **There is no such thing as AGI.** Intelligence is always specialized.
- **We should talk about rat-level, cat-level, or human-level AI (HLAI).**

Speculation: Architecture for Autonomous Intelligence

- **World Model: predicts future states**
- **Critic: predicts expected objective**
- **Cost: computes objective**
- **Perception: estimates world state**
- **Actor: computes action**

- **Humans only have one world model engine!**

- **Configurator: configures the world model engine for the situation at hand.**
  - Is this what consciousness is?



Speculations

- **Self-Supervised Learning is the future of AI / ML**
- **Models of the world: Machines need to learn them (through SSL)**
  - Perhaps common sense will emerge from learning world models
- **Emotions are (often) anticipations of outcomes**
  - According to predictions from the model of the world
- **Reasoning is finding actions that optimize outcomes**
  - Constraint satisfaction/cost minimization rather than logic
- **Consciousness may be the deliberate configuration of our world model?**
  - We only have one (configurable) model of the world
  - If our brains had infinite capacity, we would not need consciousness
- **There is no such thing as AGI.** Intelligence is always specialized.
  - We should talk about rat-level, cat-level, or human-level AI (HLAI).