The role of intrinsic motivations in learning vocal mappings

a developmental robotics study

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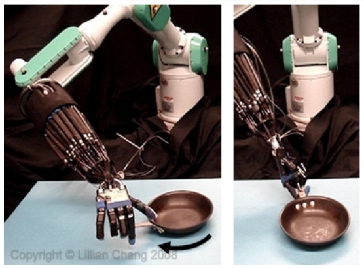
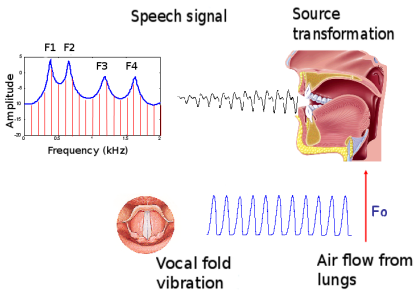
flowers.inria.fr

Why exploration strategies?





Space of motor controllers

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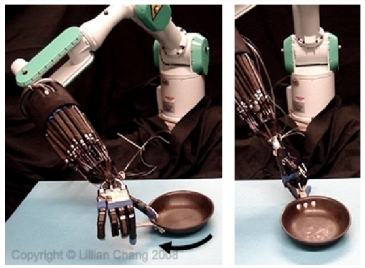

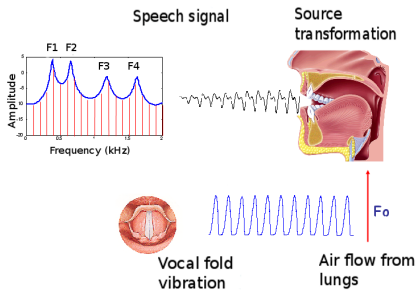

Space of motor controllers

Space of sensory effects

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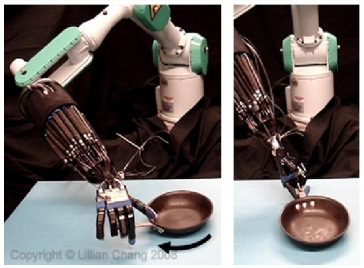

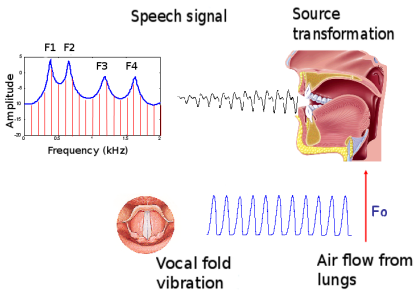

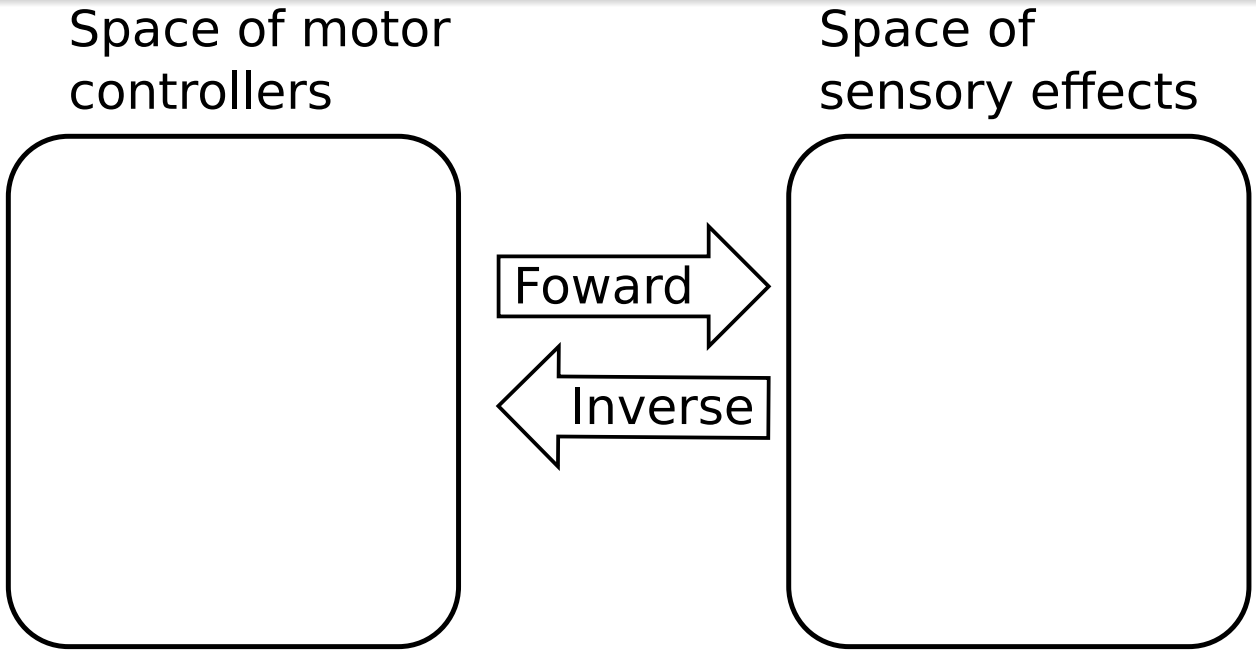

Objective: Learning forward and/or inverse sensorimotor models

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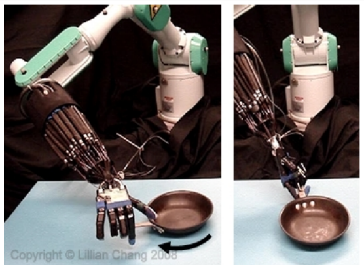

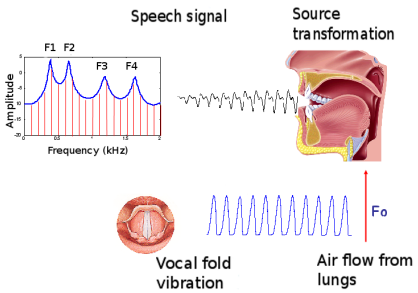

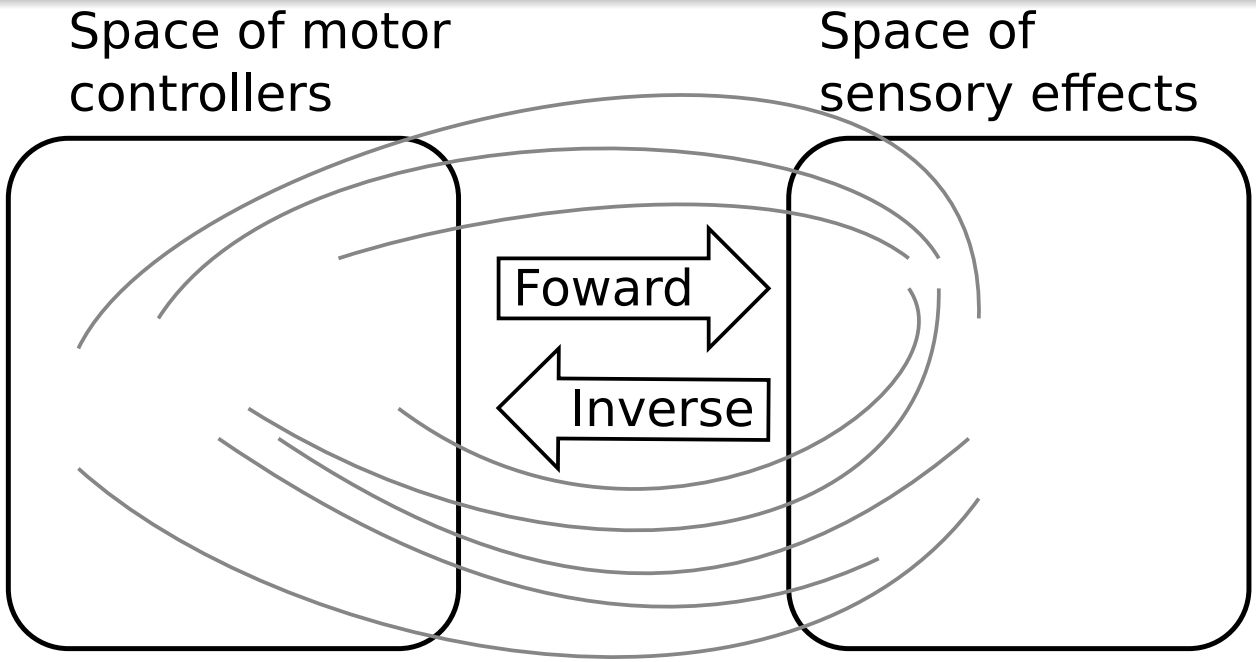

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Problems: High dimensional, non-linear, redundant, limited time

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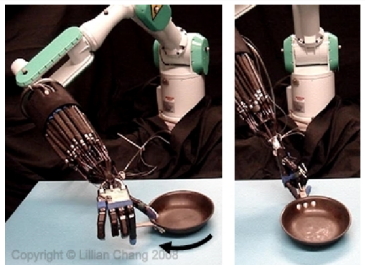

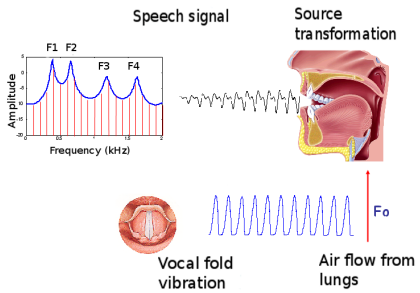

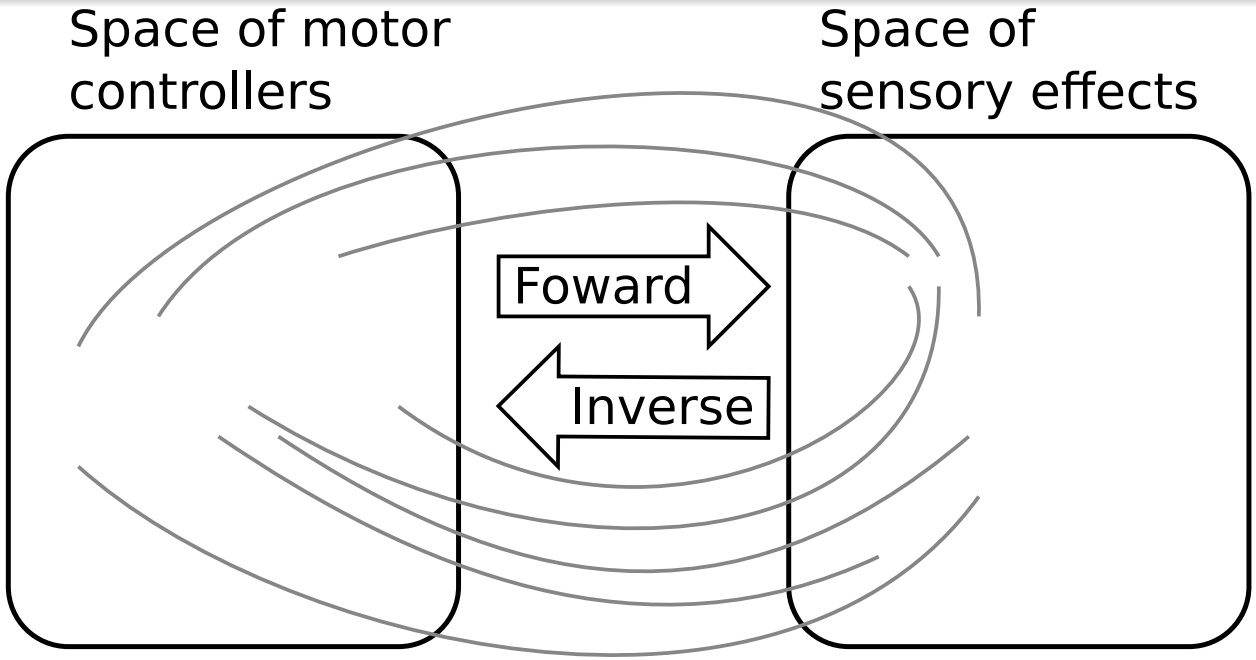

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Problems: High dimensional, non-linear, redundant, limited time

Solution: Need to drive the learning process $\Rightarrow$ exploration strategies

Two important principles

- Goal babbling
- Intrinsically-motivated (or active) exploration
  - (Schmidhuber, 2006; Oudeyer and Kaplan, 2007; Baldassare and Mirolli, 2013; Barto et al., 2004, ...)

$\Rightarrow$ Combining both principles in a unified probabilistic model
$\Rightarrow$ Relevance for infant (early vocal) development

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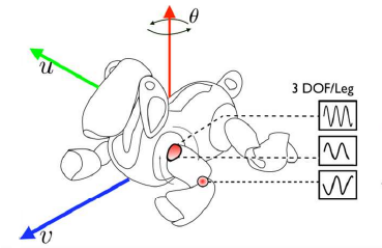

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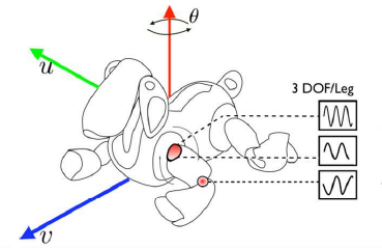

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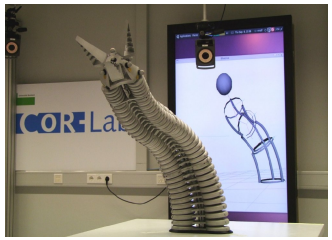

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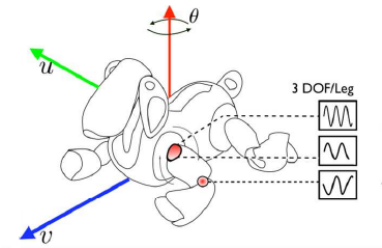

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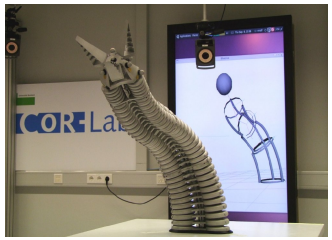

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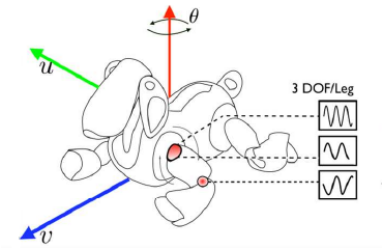

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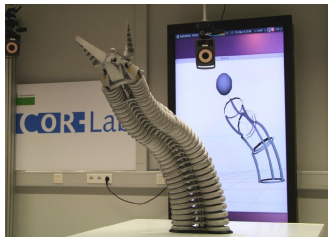

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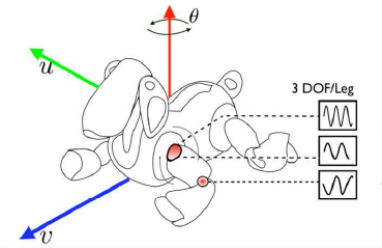

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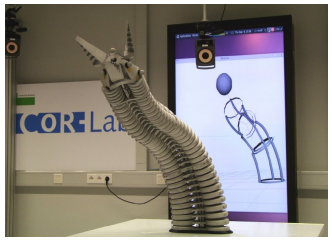

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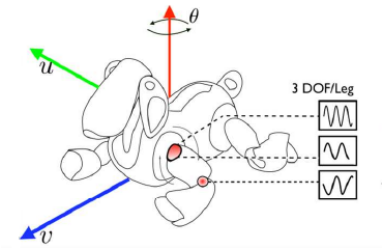

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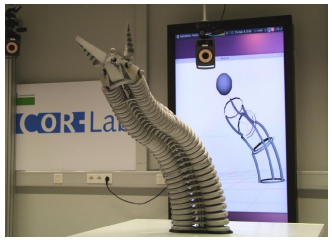

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Illustrative example

- Motor M and sensory S spaces
- Environment $s = f(m)$
  - unknown
- Motor babbling
  - Sample $m \in M$
  - Execute m
  - Observe $s = f(m)$
  - Update the model
- Goal babbling
  - Sample $s_g \in S$
  - Optimization procedure
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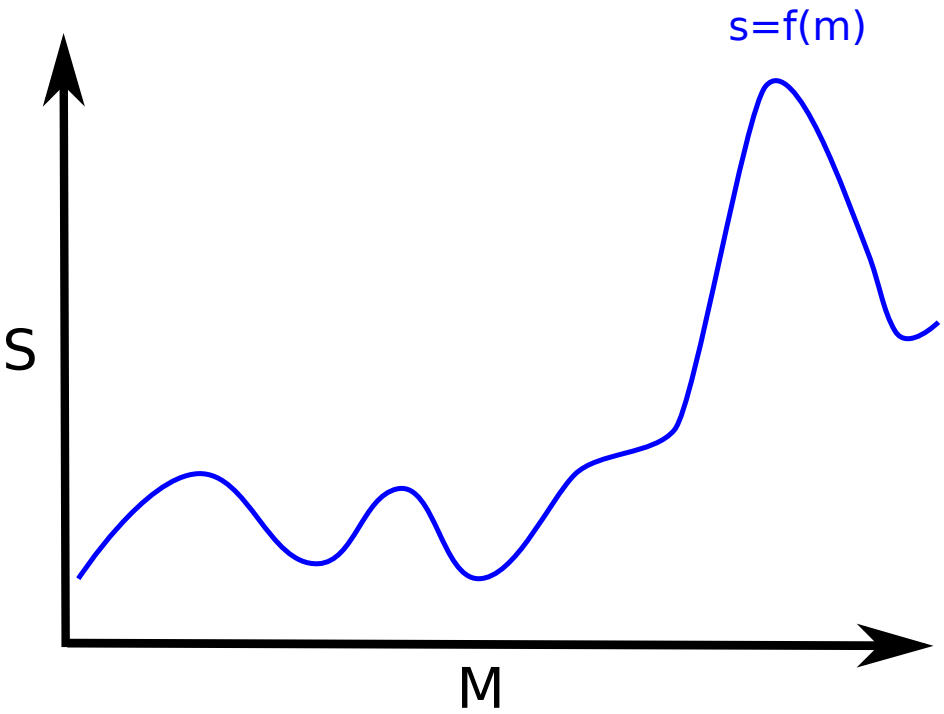

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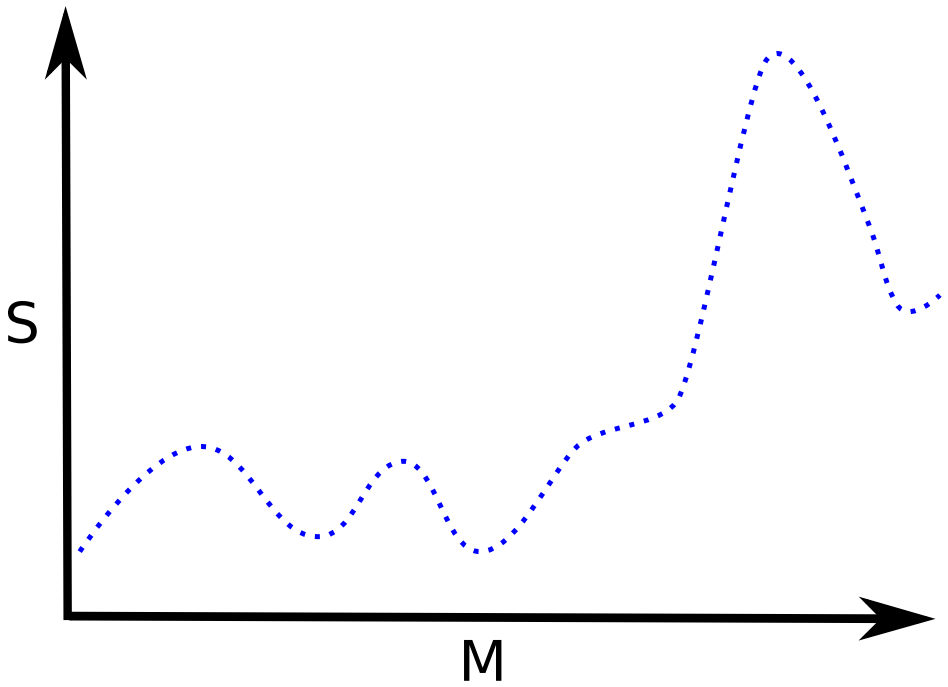

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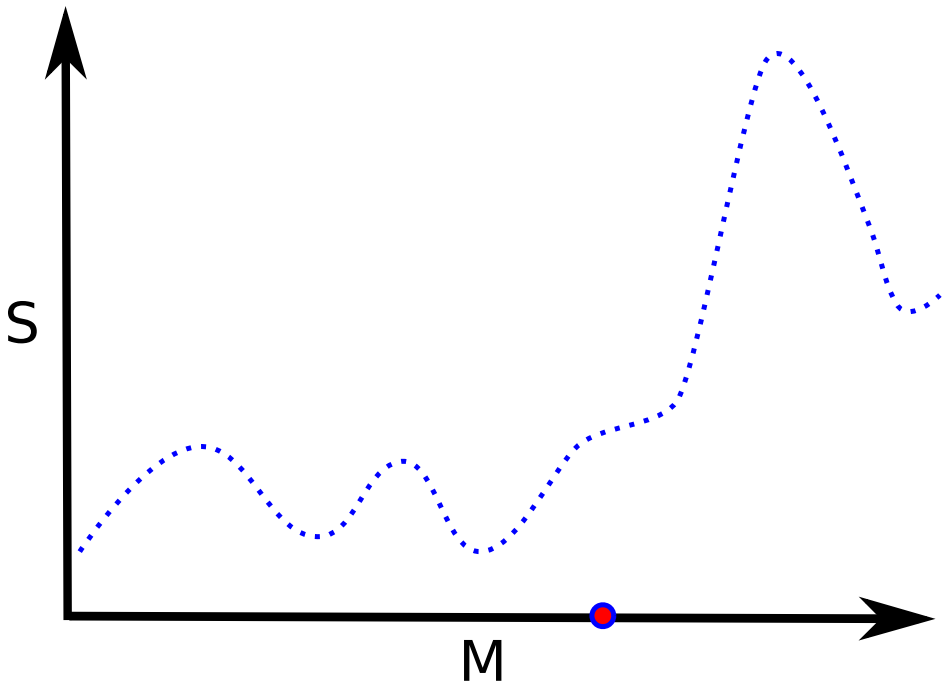

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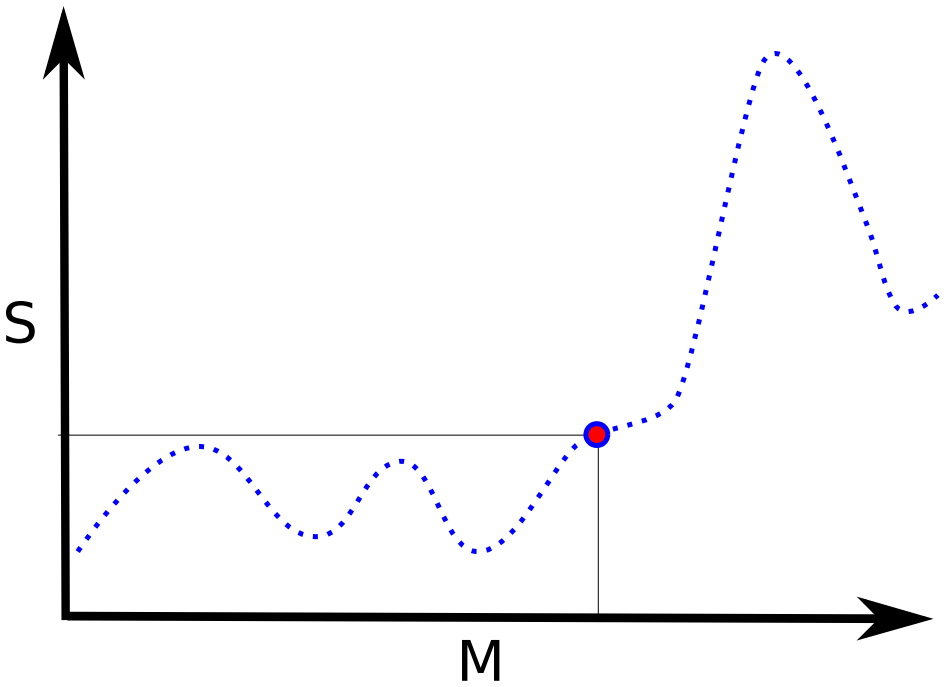

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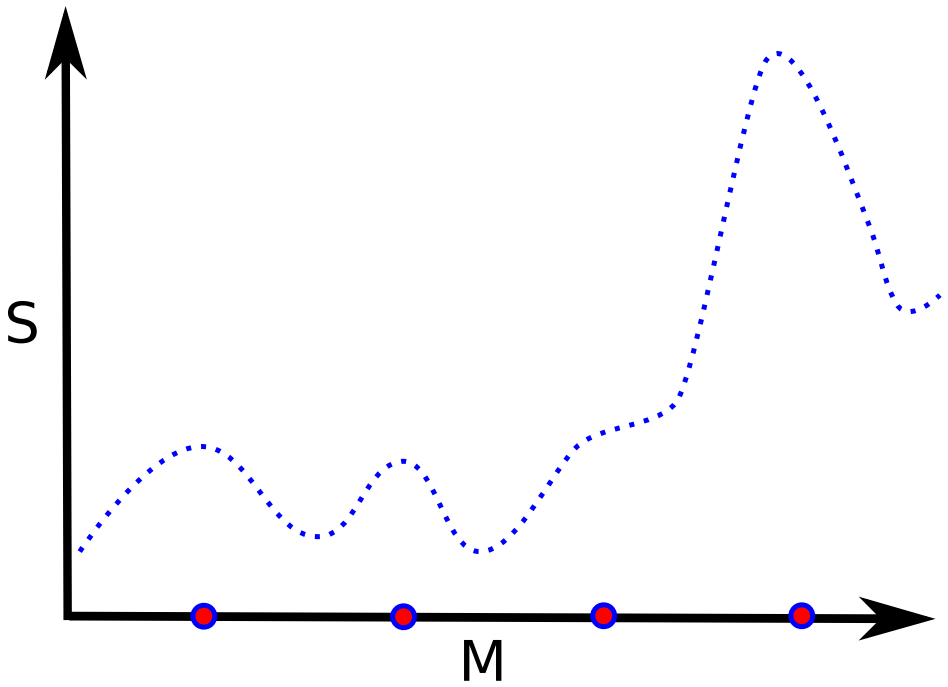

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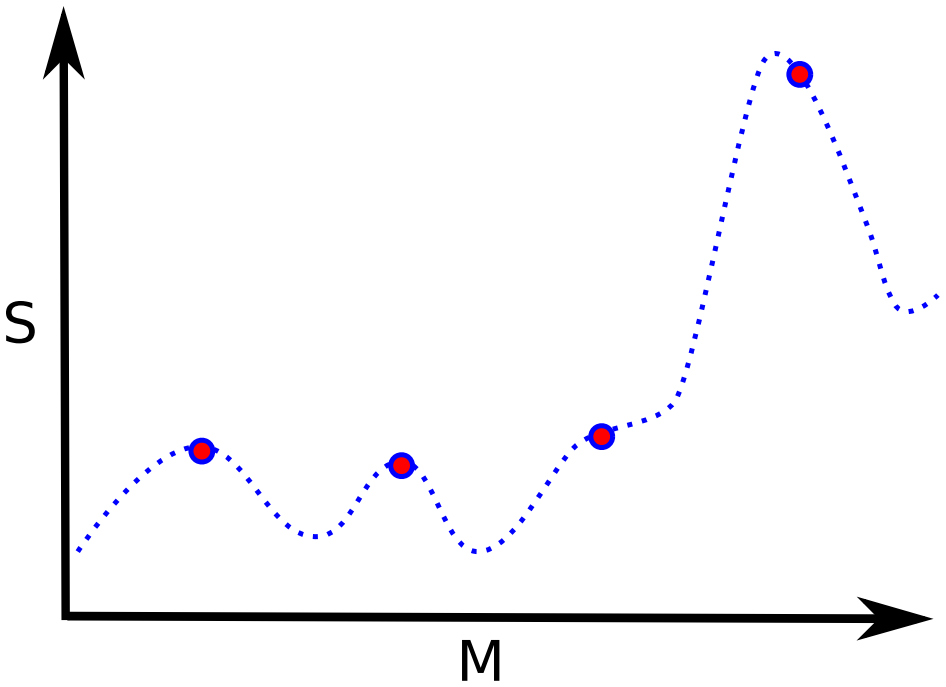

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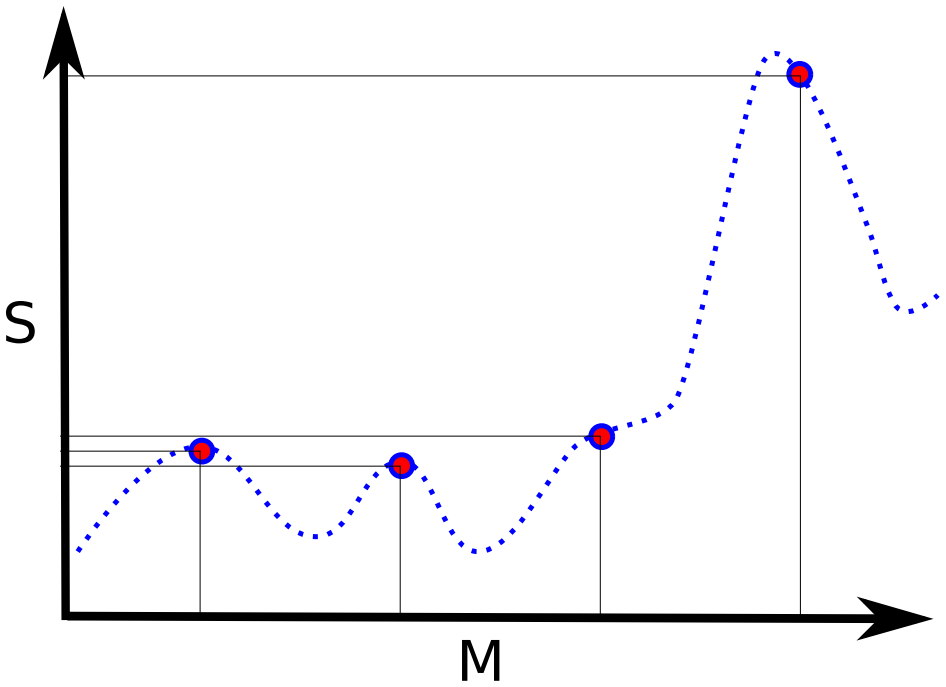

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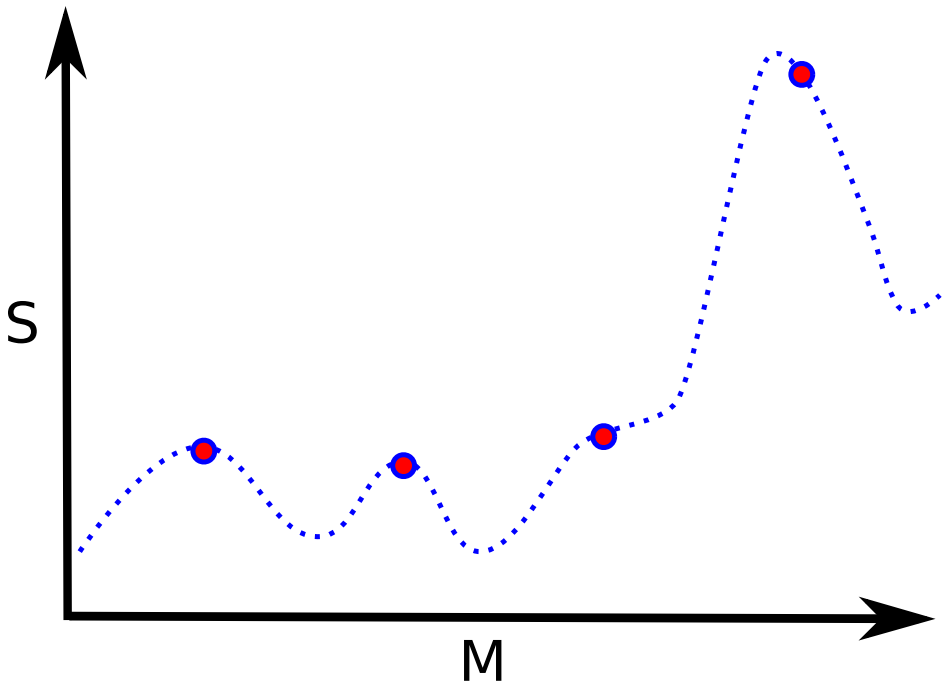

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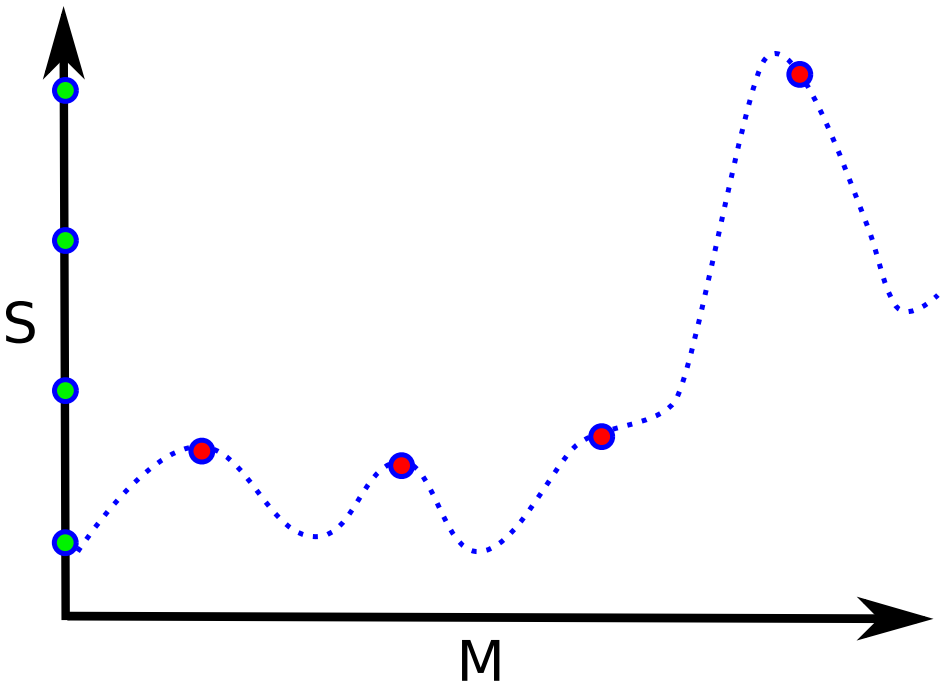

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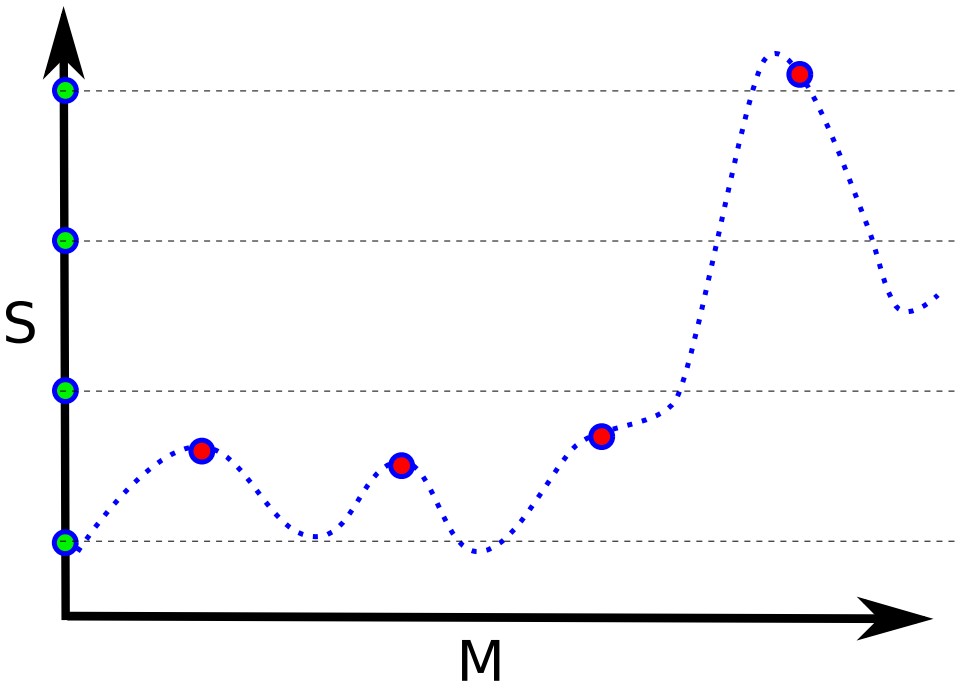

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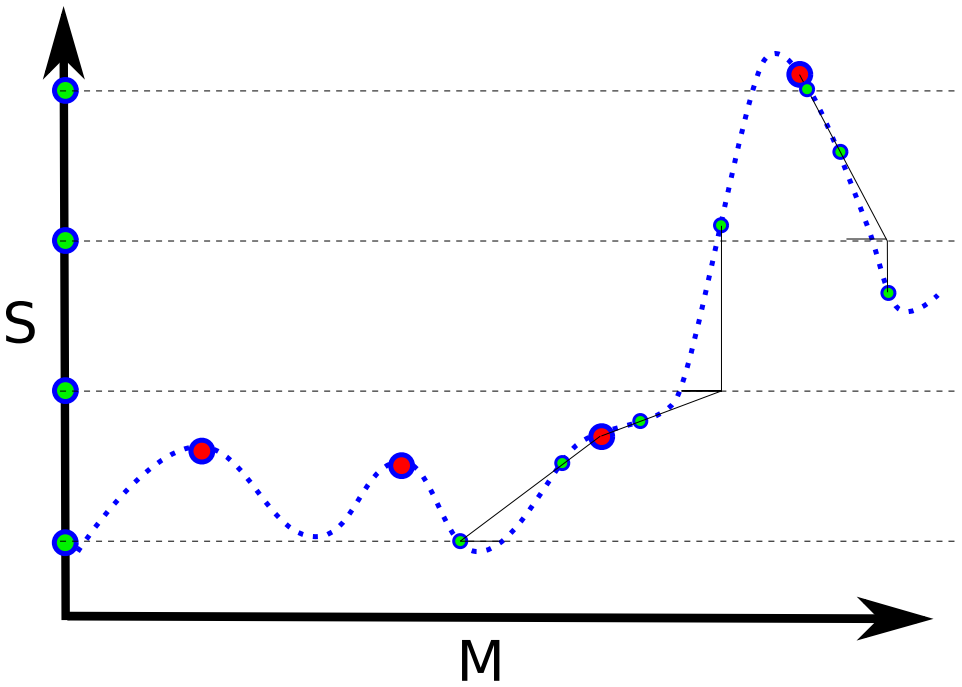

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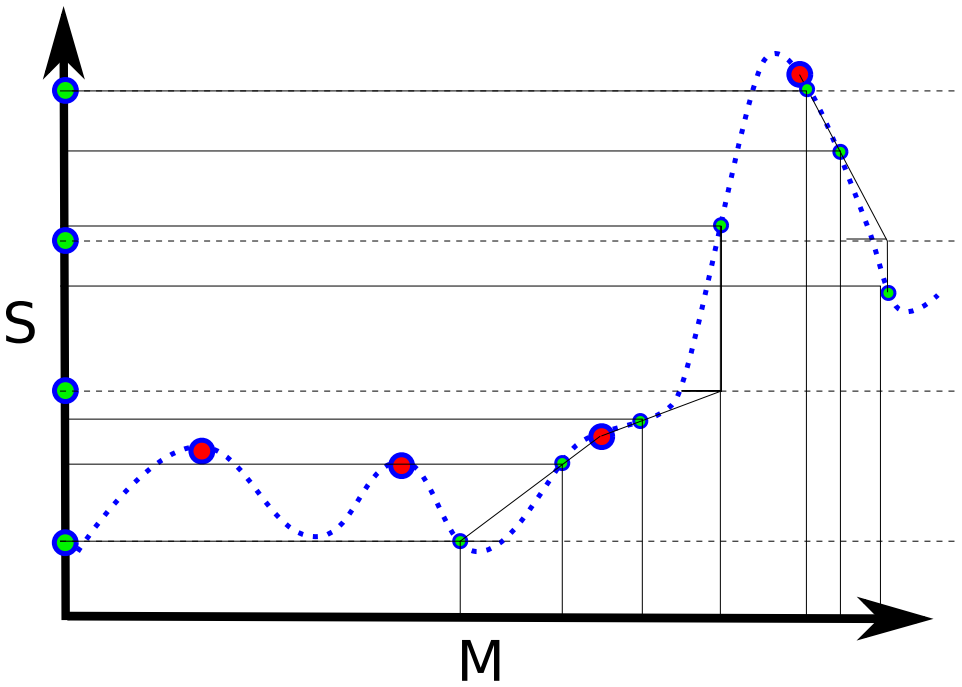

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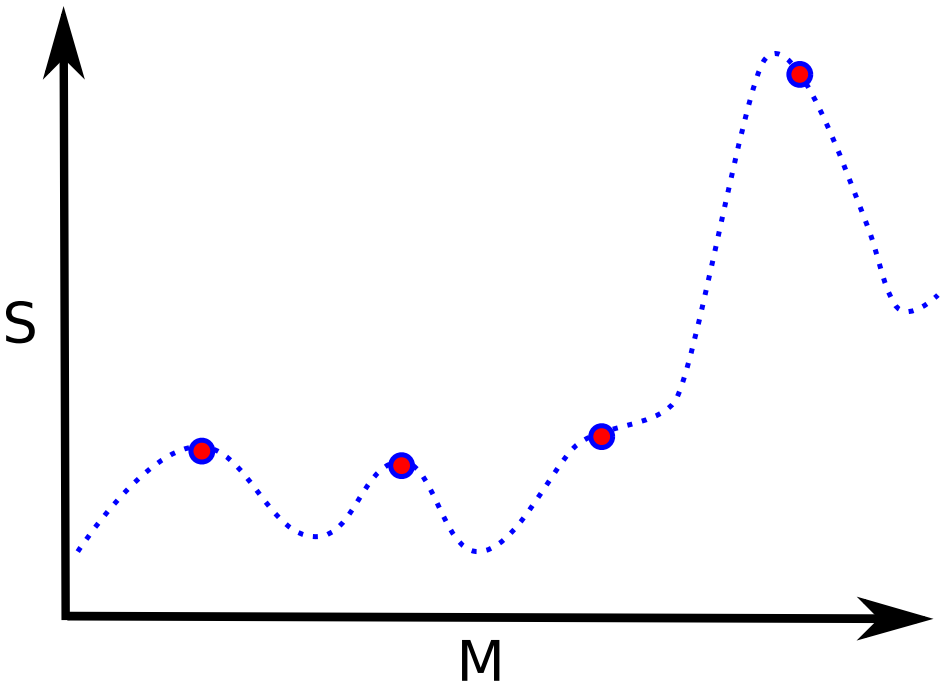

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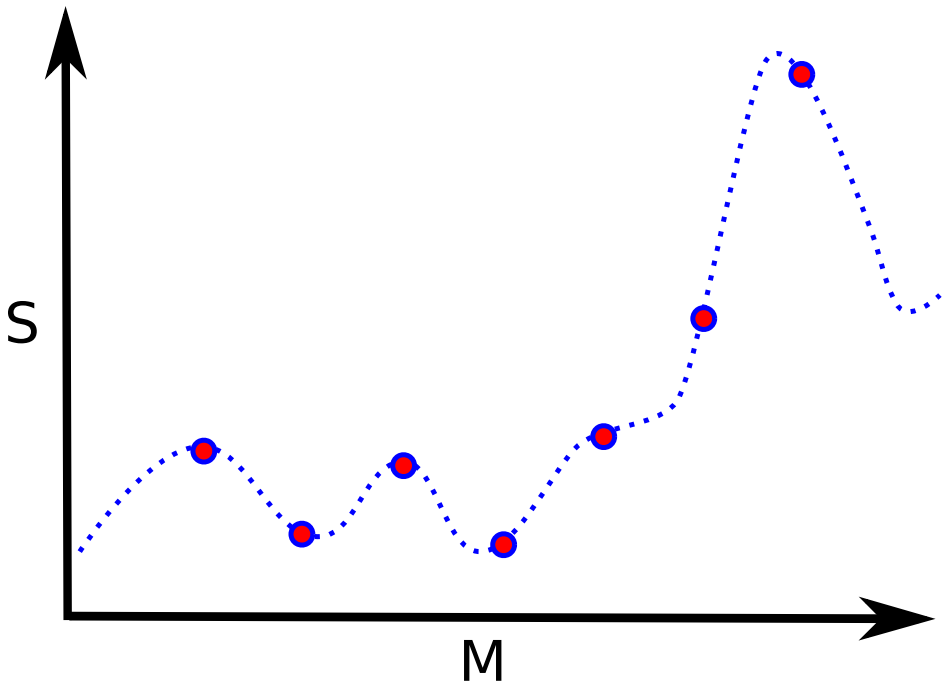

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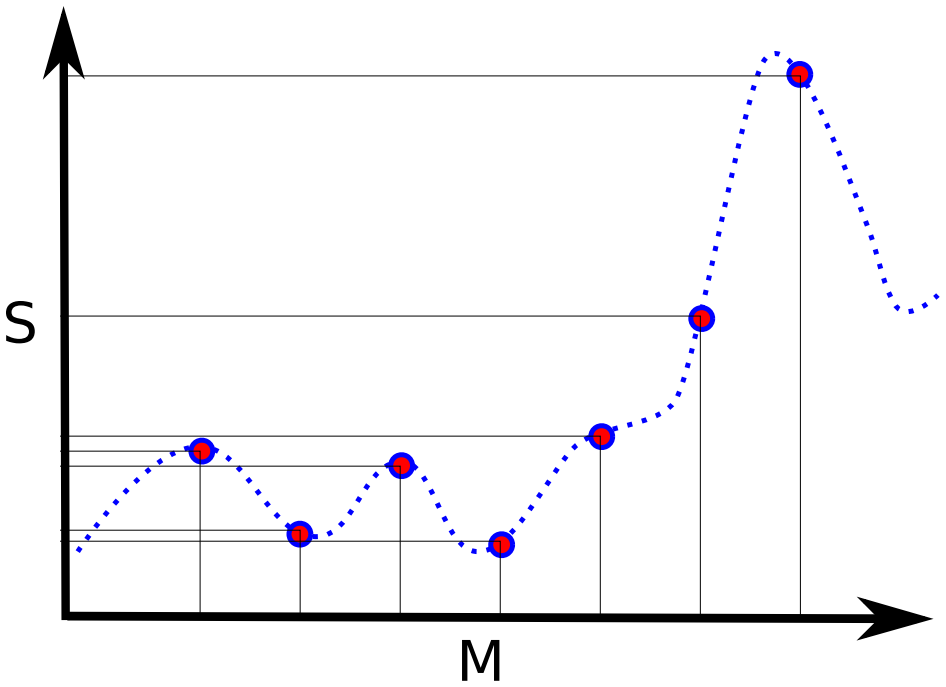

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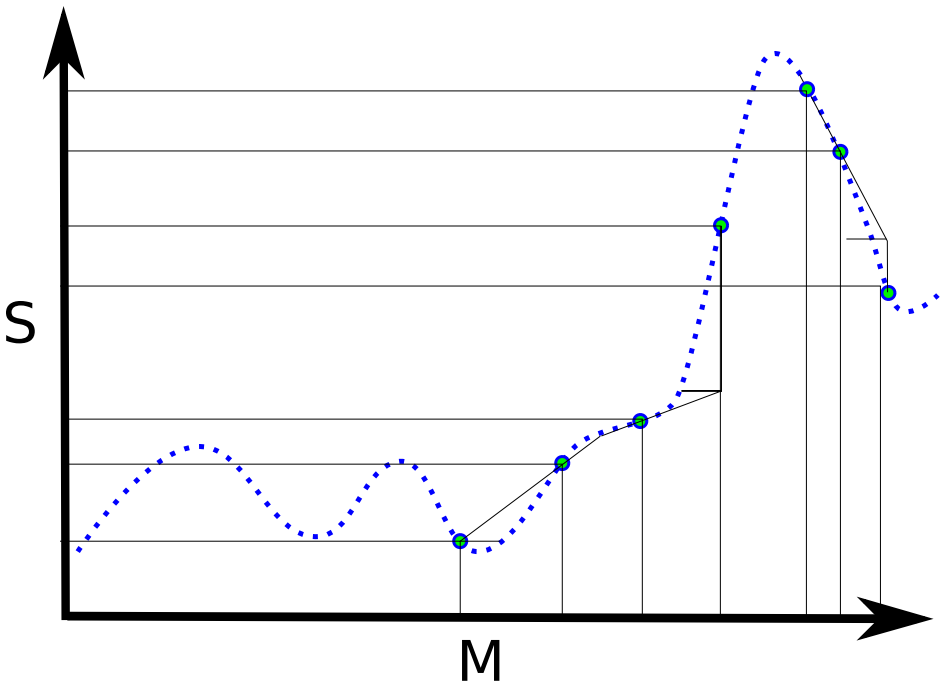

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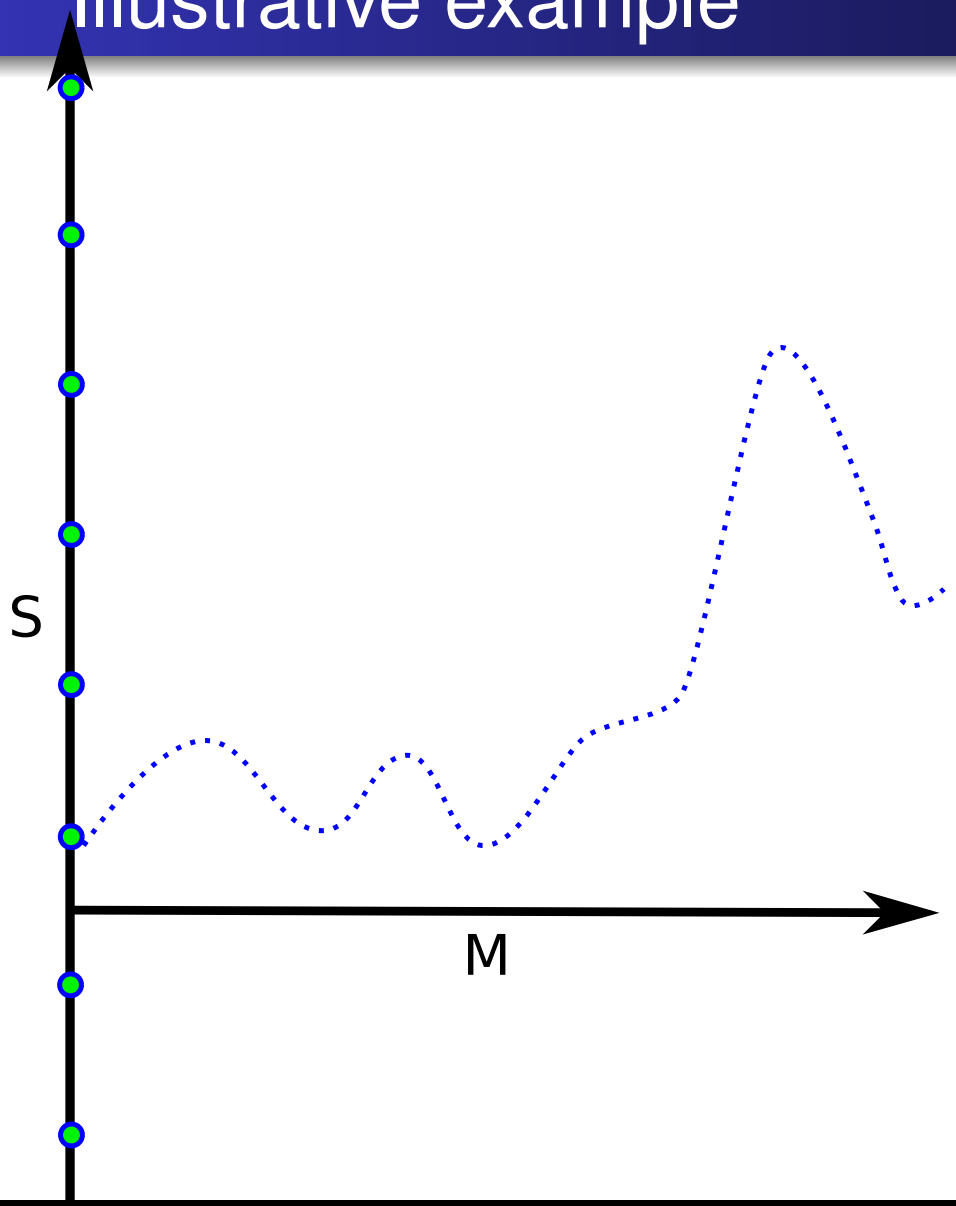
- Environment $s = f(m)$
  - unknown
- Motor babbling
  - Sample $m \in M$
  - Execute m
  - Observe $s = f(m)$
  - Update the model
- Goal babbling
  - Sample $s_g \in S$
  - Optimization procedure
  - Observe $s = f(m)$
  - Update the model

Illustrative example



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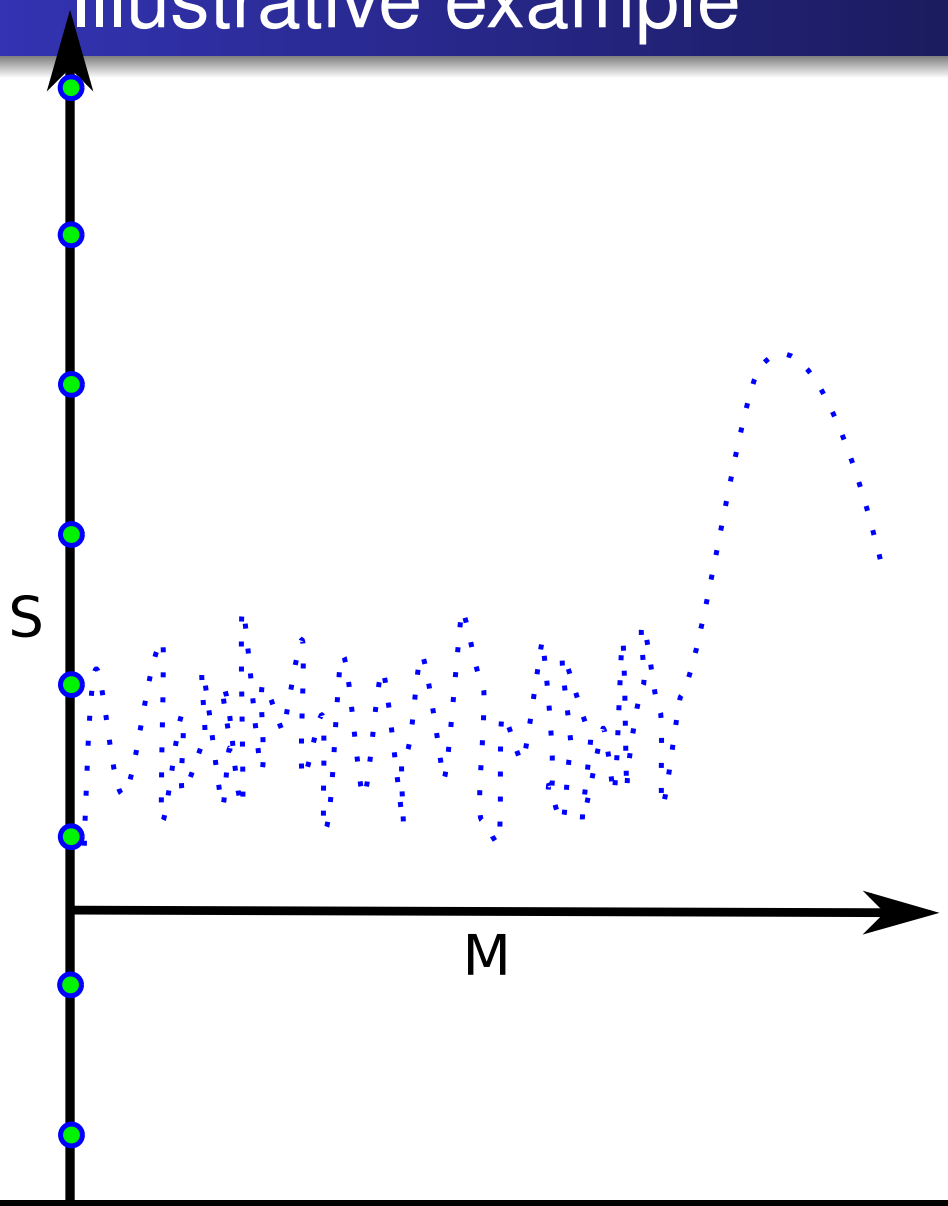

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Maximizing the learning progress

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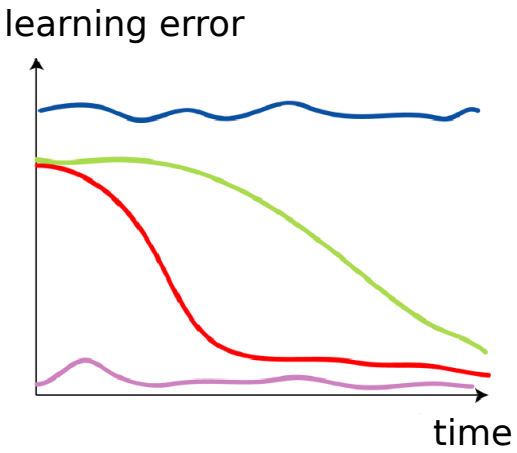

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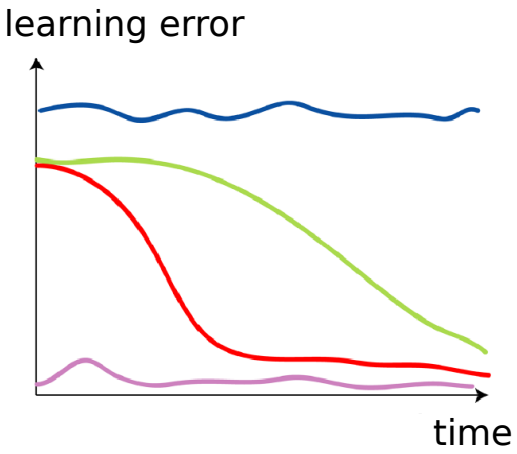

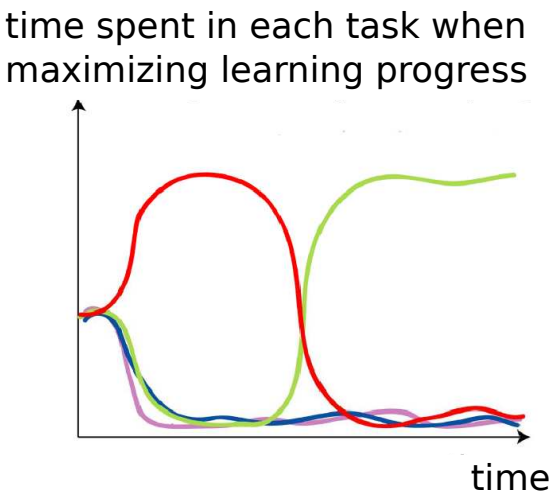

Outline

A generic exploration algorithm

Choice space X	**Interest distribution** $p(X)$	
	Random exploration	Active exploration
Motor babbling: $X = M$, $Y = S$	Random motor exploration (ACTUATOR-RANDOM)	Active motor exploration (ACTUATOR-RIAC)
Goal babbling: $X = S$, $Y = M$	Random goal exploration (SAGG-RANDOM)	Active goal exploration (SAGG-RIAC)

1: **while** true **do**
2: $x \sim p(X)$
3: $y \sim p(Y \mid x)$
4: $m = M((x, y))$
5: $s = f(m) + \epsilon$
6: $e = distance(S(x, y), s)$
7: $update(p(M\ S), (m, s))$
8: $update(p(X), (x, e))$
9: **end while**

A generic exploration algorithm

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A generic exploration algorithm

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Sensorimotor model
p(M S)

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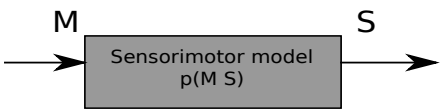

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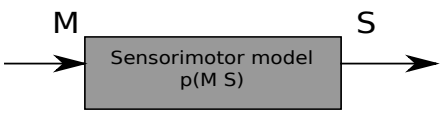

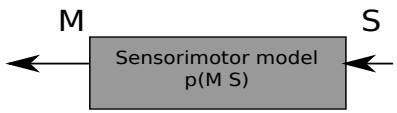

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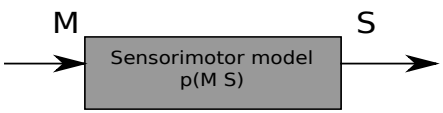

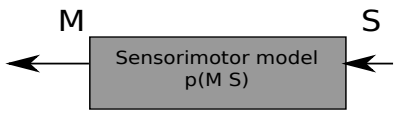

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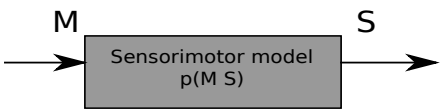

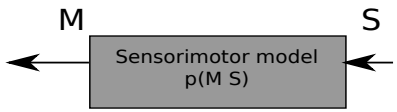

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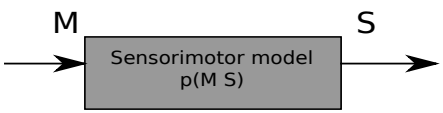

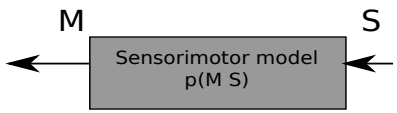

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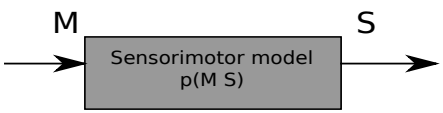

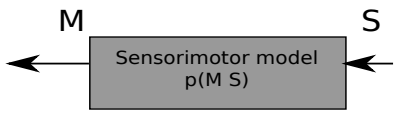

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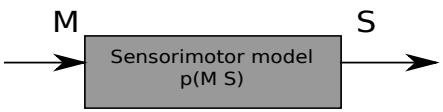

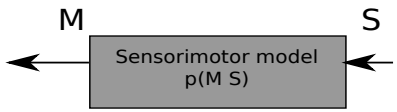

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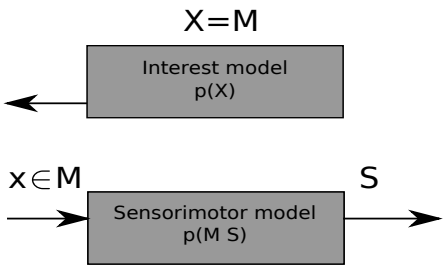
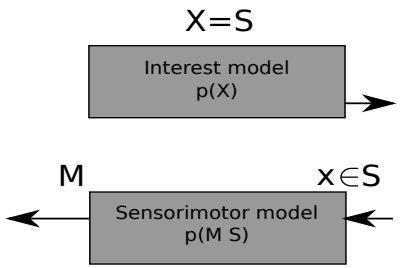
Motor babbling



Goal babbling



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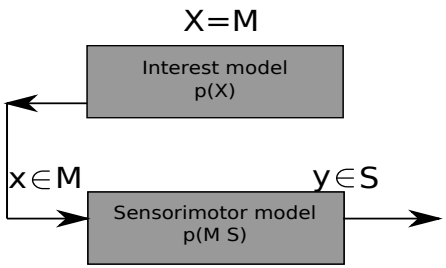
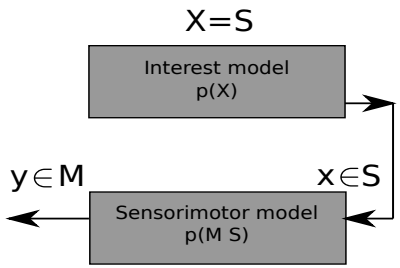
Motor babbling



Goal babbling



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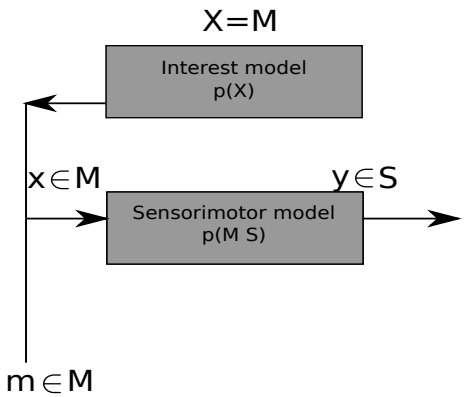
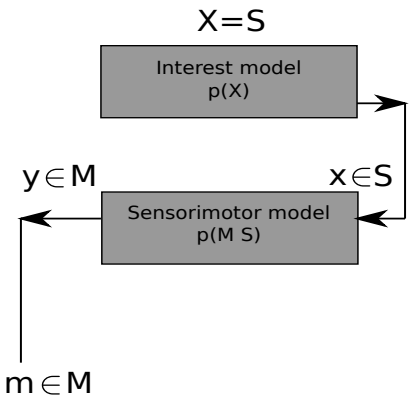
Motor babbling



Goal babbling



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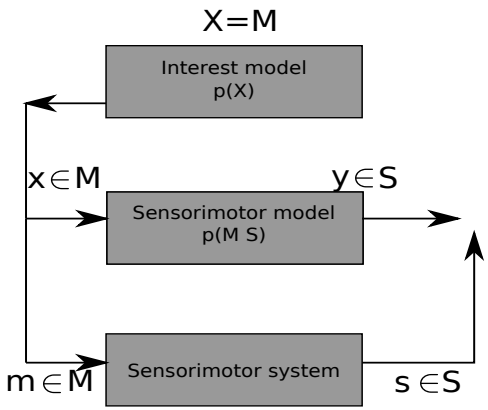

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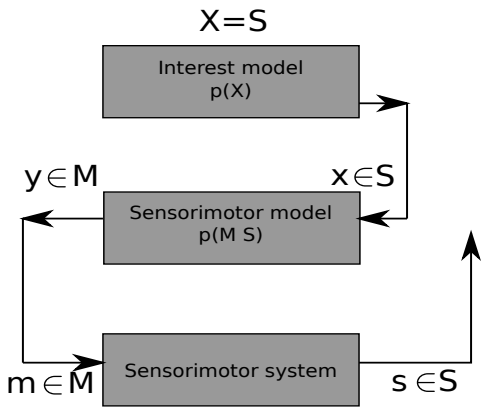

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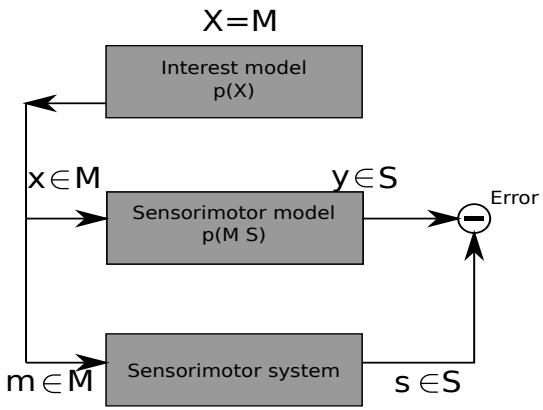

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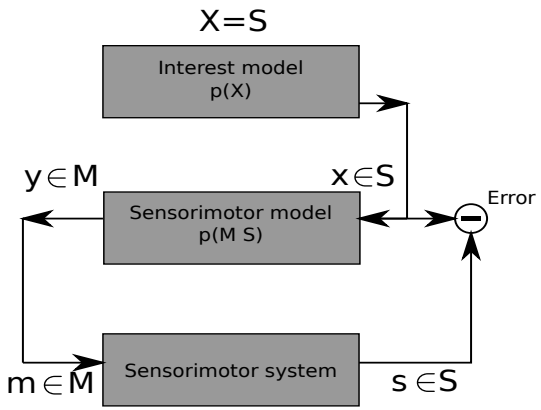

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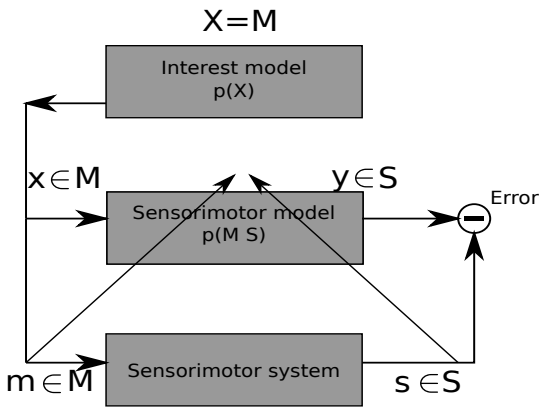

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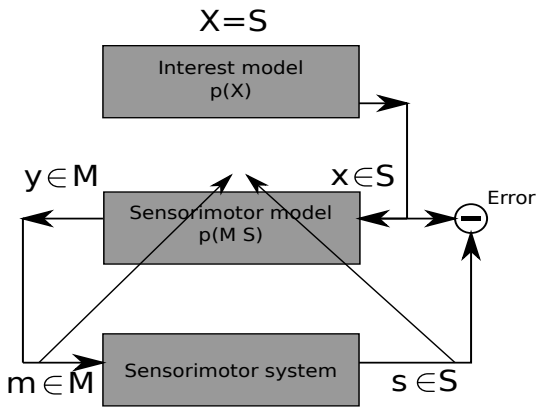

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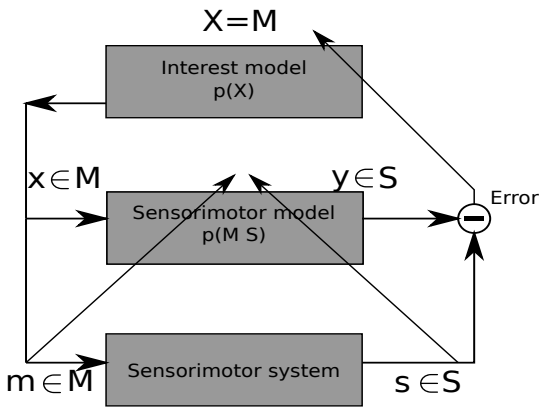
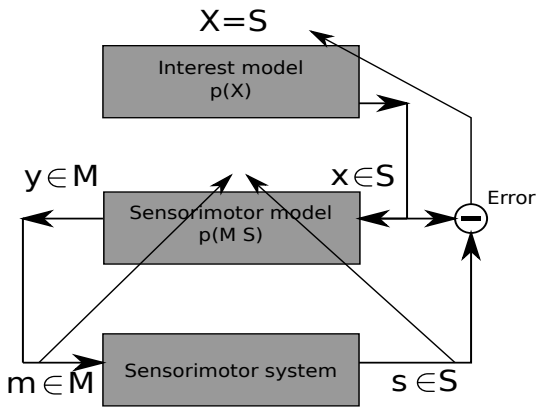


Goal babbling



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Outline

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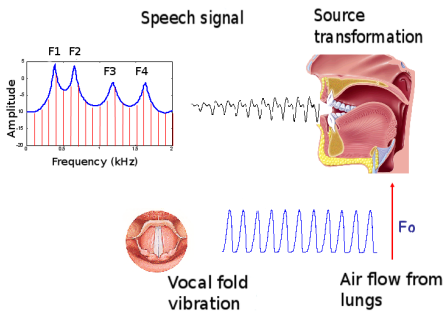

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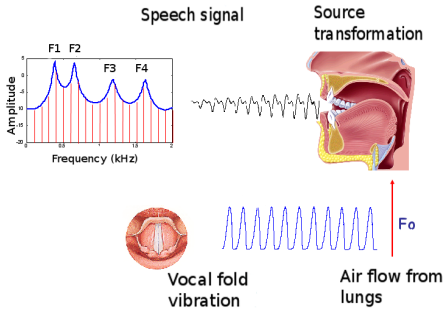

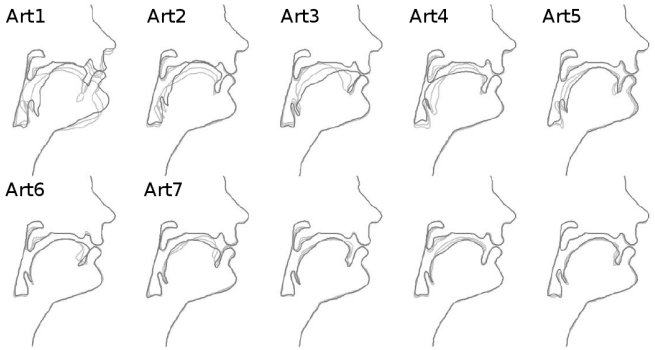

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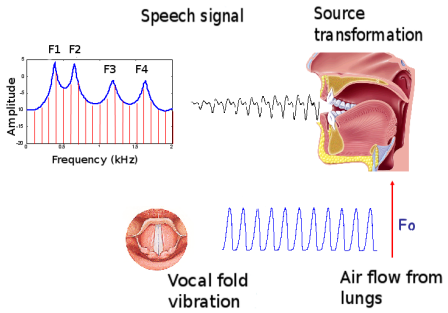
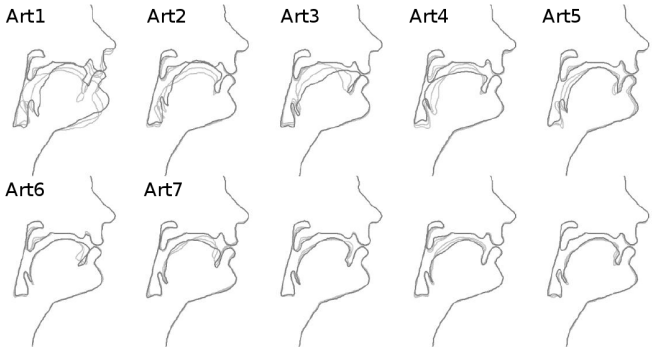
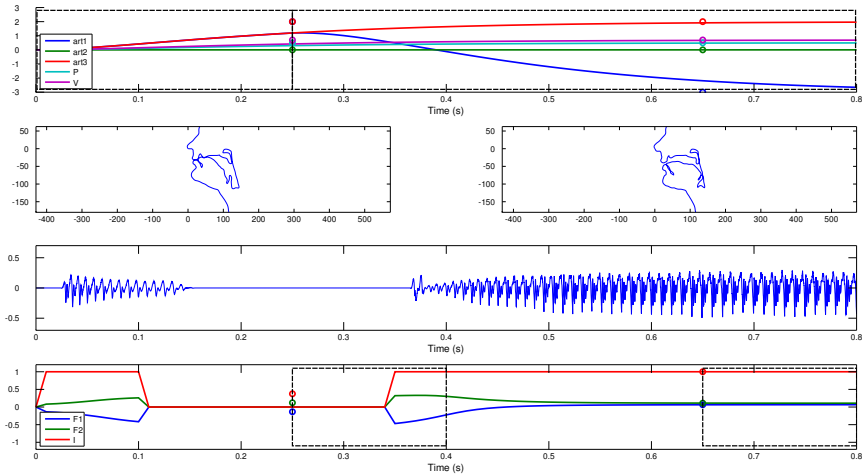
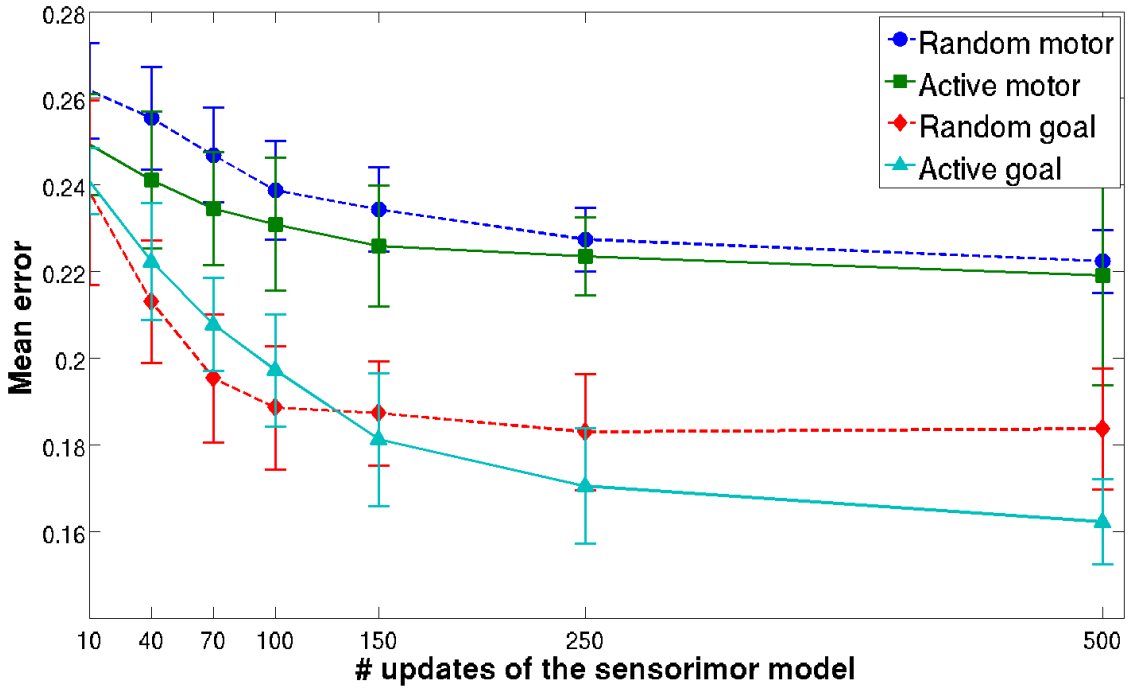






Performance comparison



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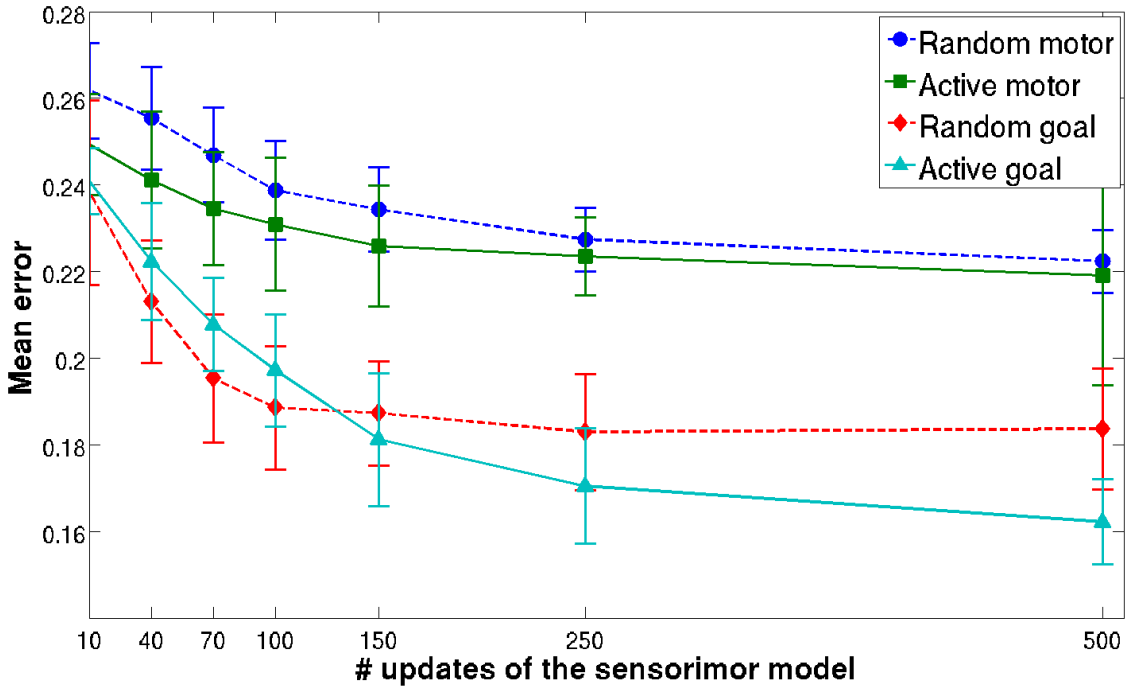

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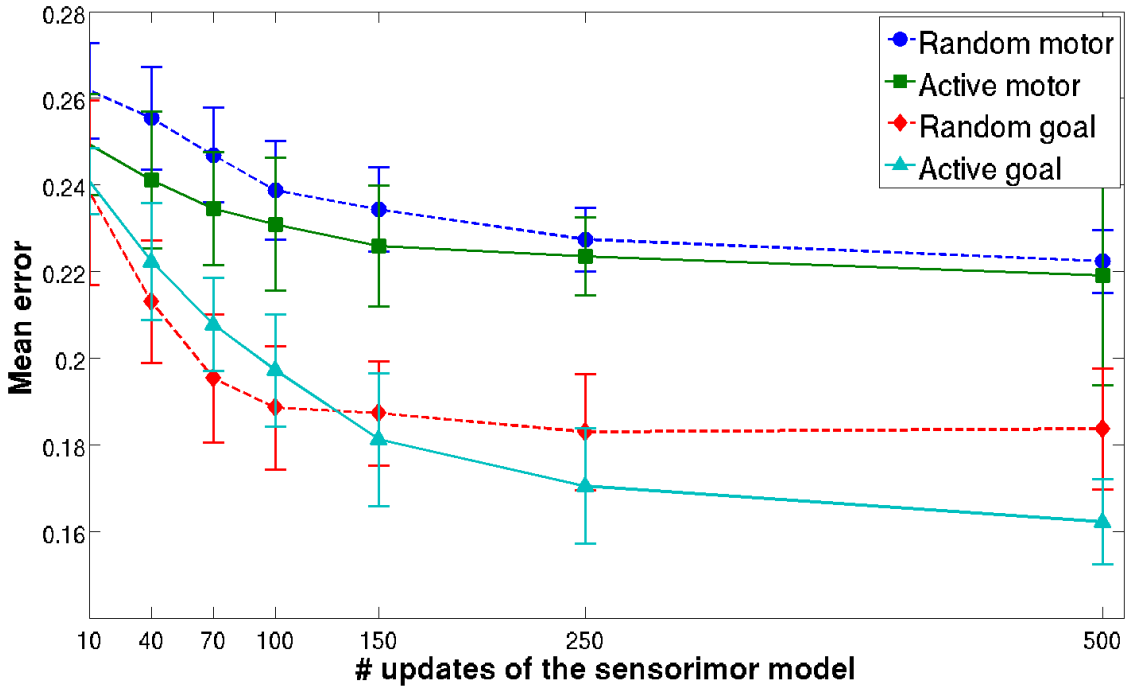

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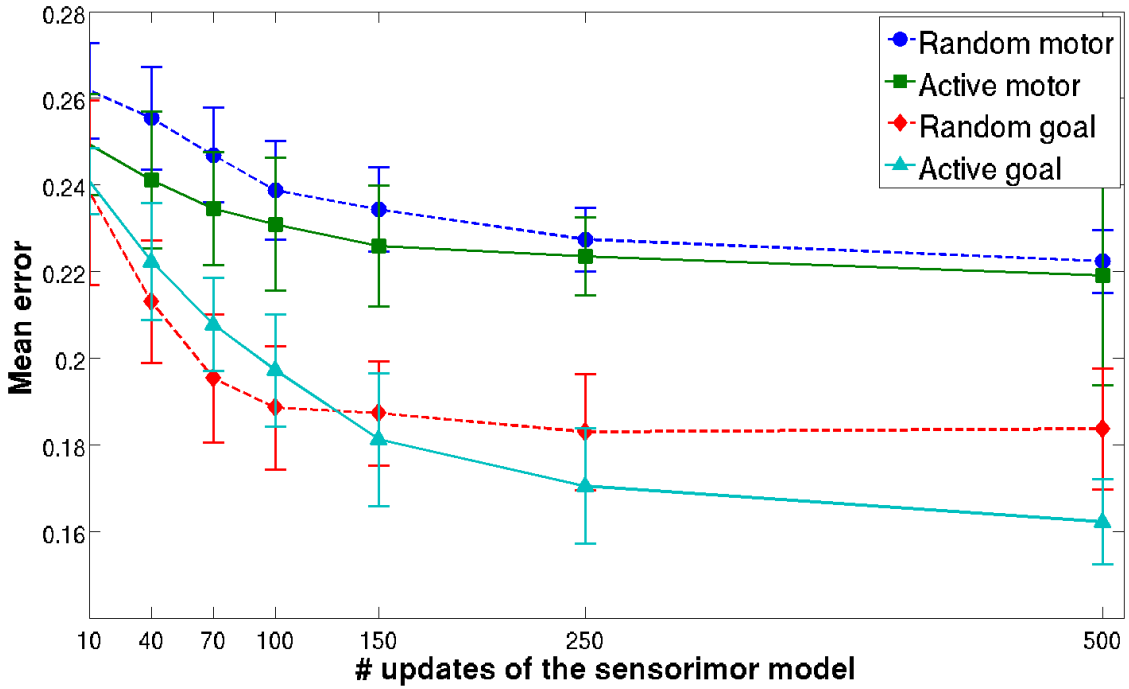

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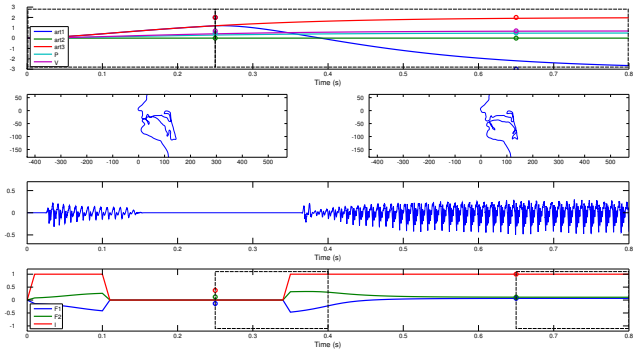
Self organization of early vocal development



- Active goal exploration enables the self-organization of a developmental sequence, from simple to complex

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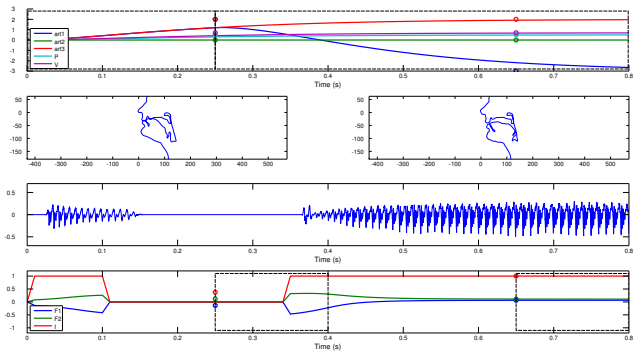

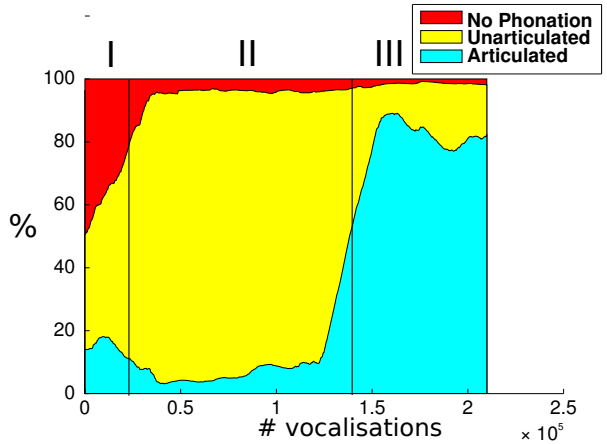

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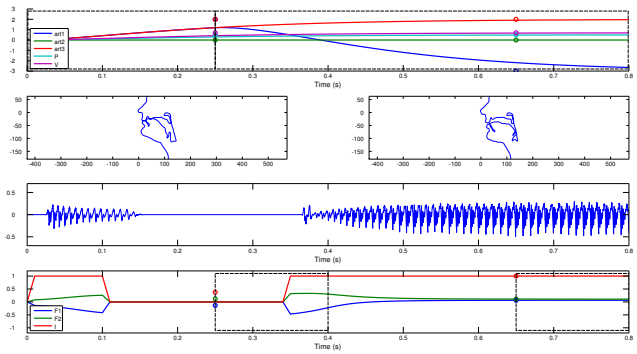

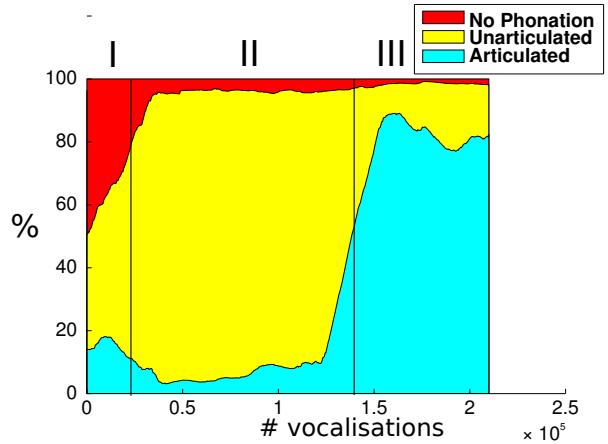

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Take-home messages

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- These principles (e.g. goal babbling and intrinsically-motivated exploration, but also maturations, social guidance ...) are grounded in developmental psychology
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- Extending the unification to more developmental robotics principles, e.g. social guidance and maturations.
- Using a physical model of the vocal tract

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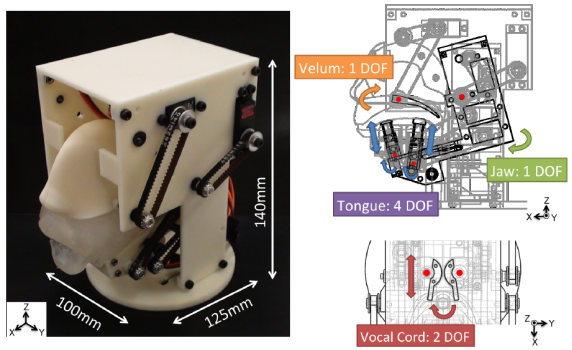

(Yuki et al., ICDL-Epirob 2013)

Thank you for your attention. Any question?

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