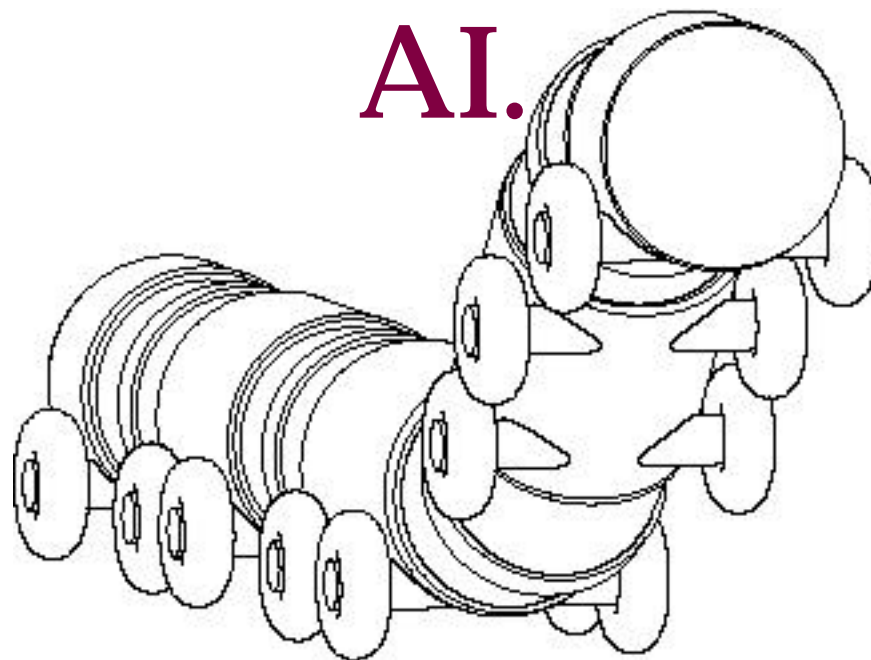


# What Sewers Tell Us About Behavior-Oriented AI.



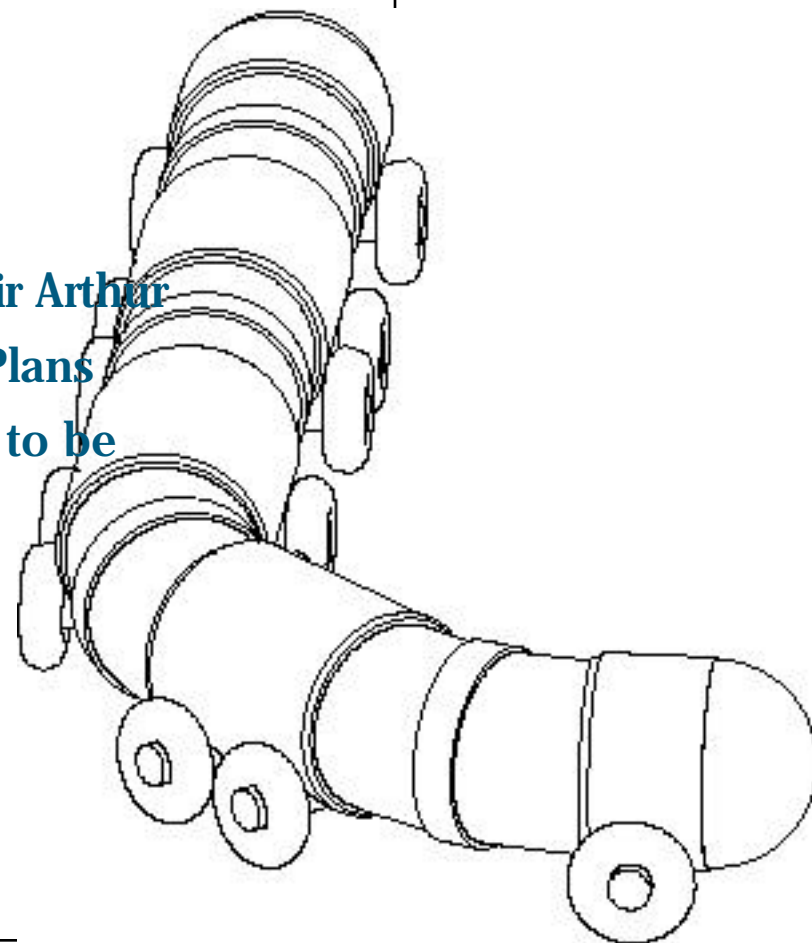
**Thomas Christaller**

**Institute on Autonomous intelligent Systems (AiS)**

**GMD—German National Research Center for  
Information Technology, Sankt Augustin**

# Structure of the Talk

- **The Application: Sewerage Systems**
- **First Steps: KURT, LAOKOON, MAKRO, Sir Arthur**
- **The Methodology: Dynamic Systems + Plans**
- **The Basic Question: Why does it pay off to be intelligent?**
- **Summing Up**



# A Complex Environment: The Sewage Testbed



- 400,000 km communal sewage systems in Germany
- e.g. 5,000 km in Hamburg
- 1.20 m and below diameter ca 80%
- must be inspected completely every 10 years
- costs ca 17 DM/m
- testbed ca 90 m, 60 cm Ø, with damages, dry and new
- sponsored by rhenag, Cologne
- LAOKOON feasibility study funded by BMBF in 1996



# KURT in the Testbed

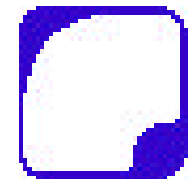


developed and  
constructed by Frank  
Kirchner  
20 x 30 cm  
6 wheels  
sensors: ultrasonic,  
inclinometers, battery  
level, shaft encoder

# Project MAKRO. Overview



- **Mehrsegmentiger Autonomer KanalROboter**
  - (Multi-Segment Autonomous Sewer Robot)
- **Grant #:** BMBF 02-WK9702/4
- **Term:** October 1997–September 2000
- **Funding:** DM 1,232,750
- **Partners:**
  - rhenag, Cologne
  - Forschungszentrum Informatik (FZI), Karlsruhe
  - Inspector Systems Rainer Hitzel, Rödermark
  - GMD – National Research Center for Information Technology, Sankt Augustin



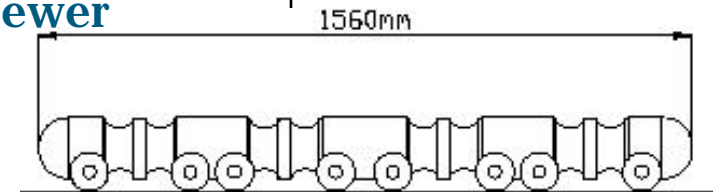
**INSPECTOR**  
SYSTEMS

# Project MAKRO. R&D Goals



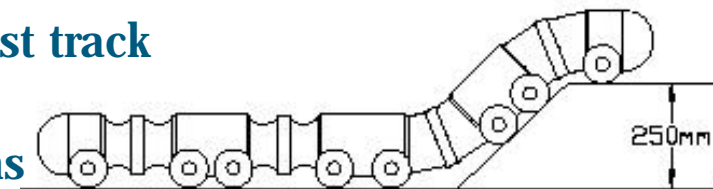
- **Development of a multi-segment, autonomous sewer robot platform**

- Ability to drive autonomously inside real sewers
- Ability to turn into branching pipes
- Ability to climb steps



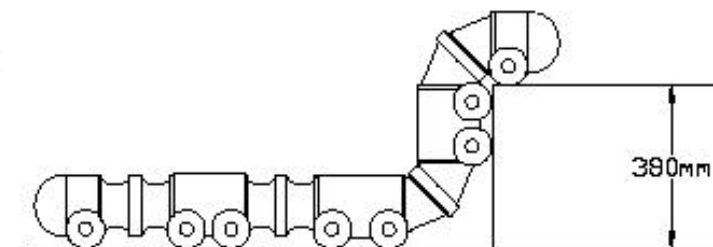
- **Final test: driving safely through an 800 meter test track in a Siegburg sewer**

- **Long term goal: platform as carrier of applications (inspection, monitoring)**



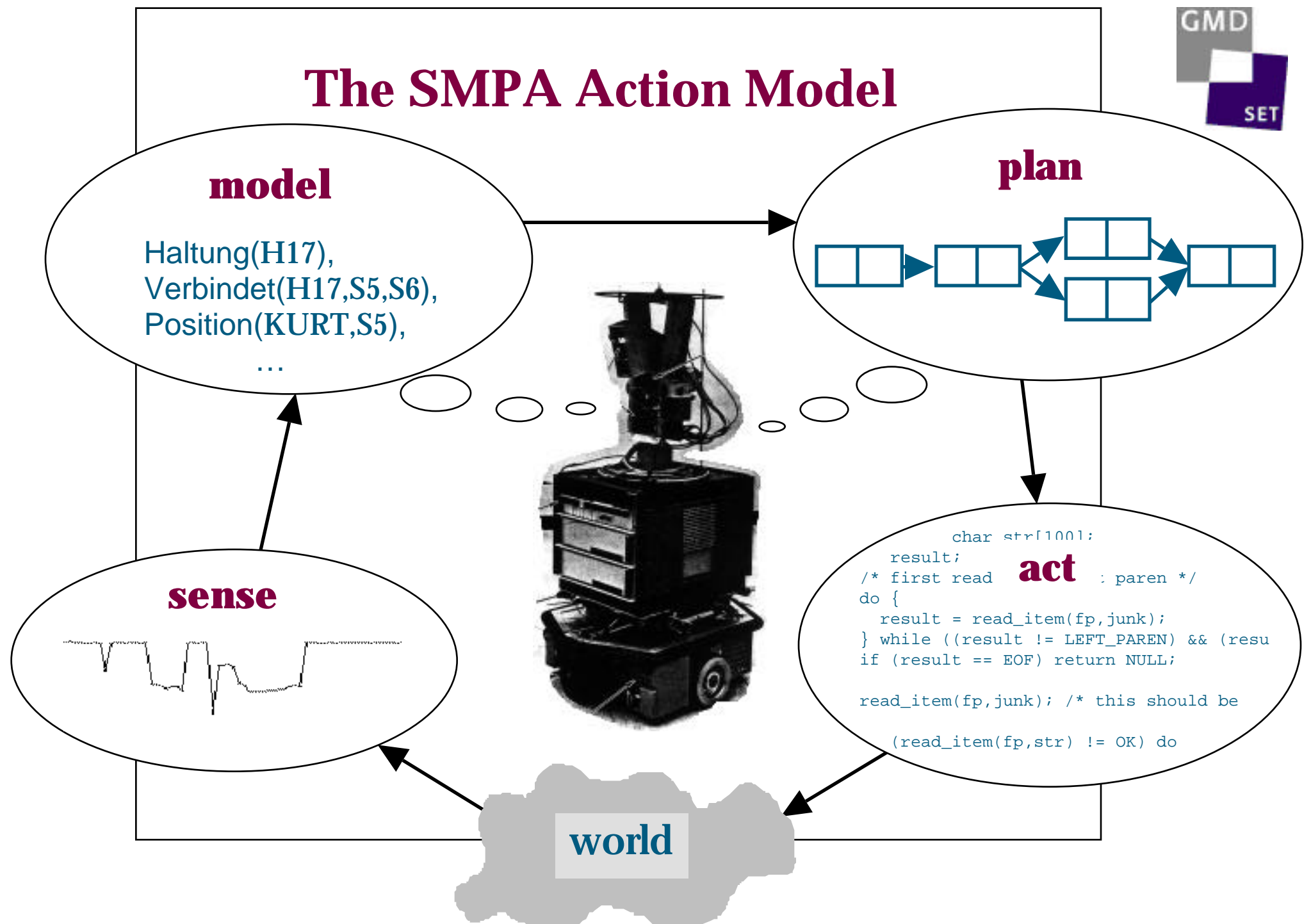
- **Assumed Sewer Conditions for Robot Operation:**

- Pipe diameters 300 – 600 millimeters (12 to 24 inches)
- Dry weather conditions
- Coarsely cleaned sewer



- **Reduce inspection costs by a factor of 4: DM 4 instead of DM 16 per meter**

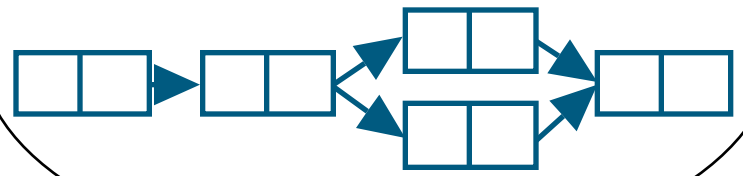
# The SMPA Action Model



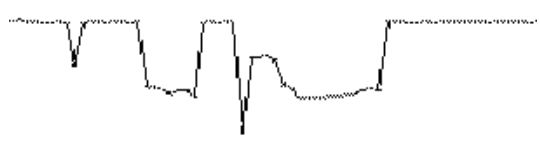
## model

Haltung(H17),  
Verbindet(H17,S5,S6),  
Position(KURT,S5),  
...

## plan



## sense



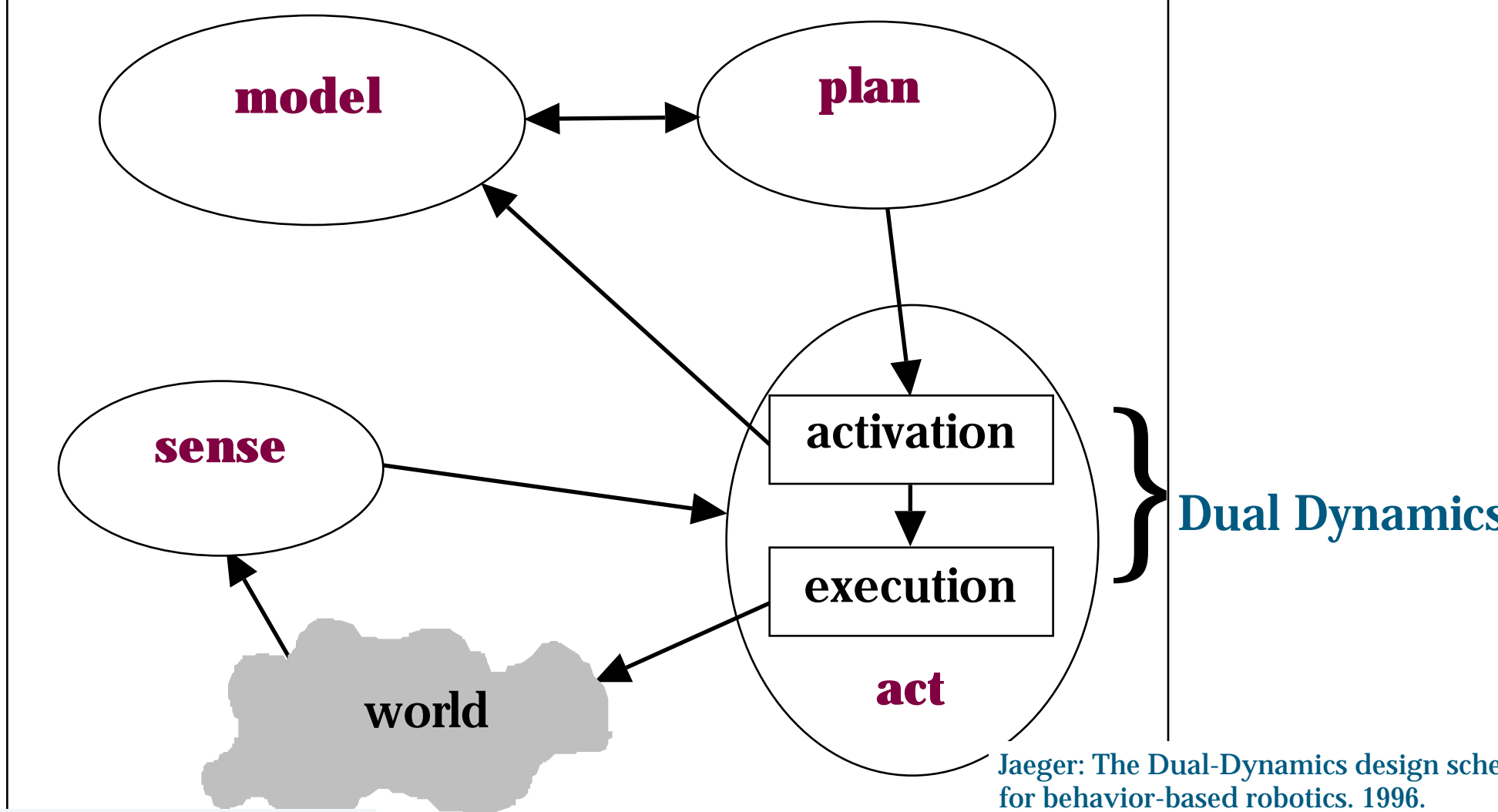
## act

```
char str[1001];
result;
/* first read act : paren */
do {
    result = read_item(fp,junk);
} while ((result != LEFT_PAREN) && (resu
if (result == EOF) return NULL;

read_item(fp,junk); /* this should be
(read_item(fp,str) != OK) do
```

world

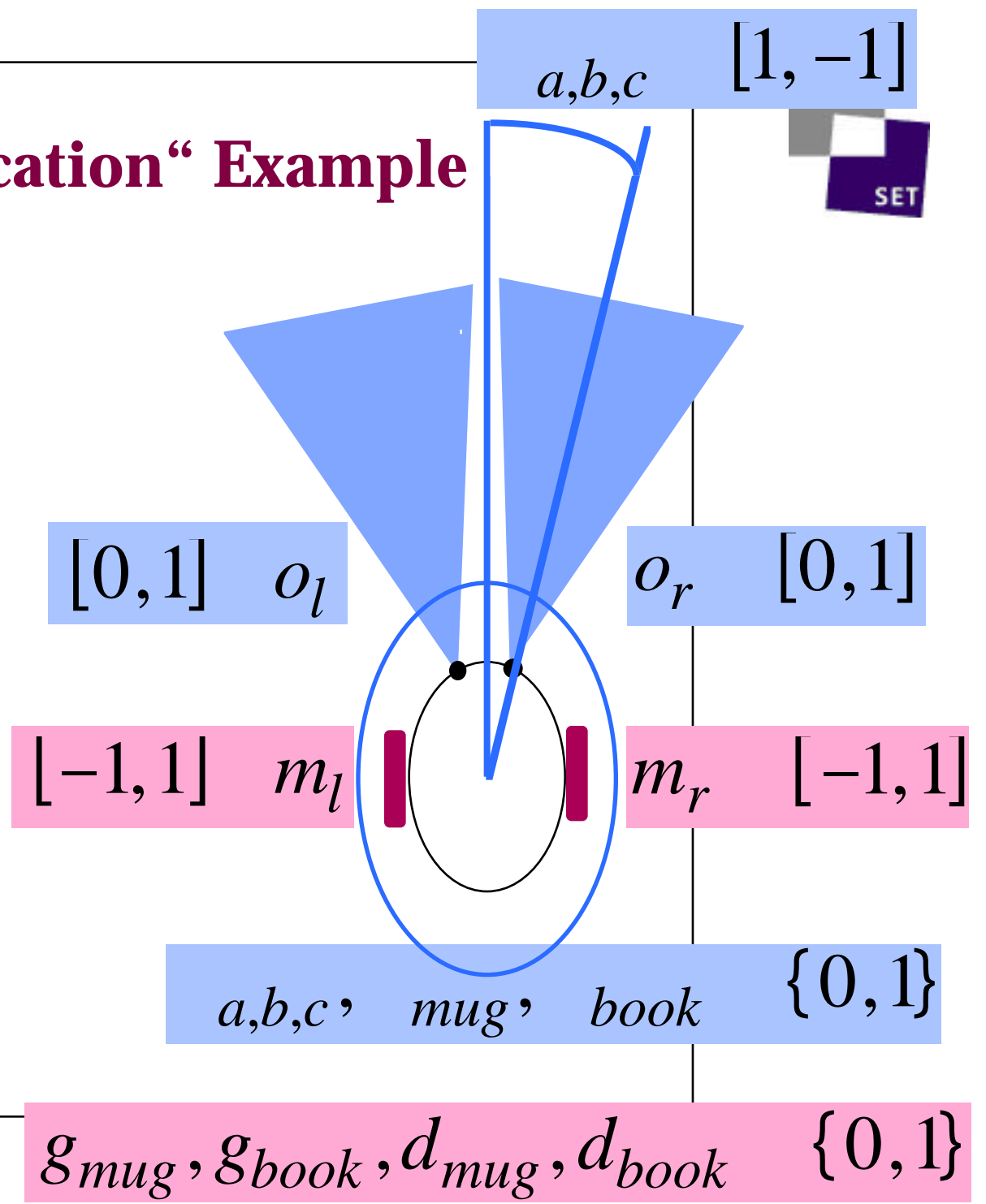
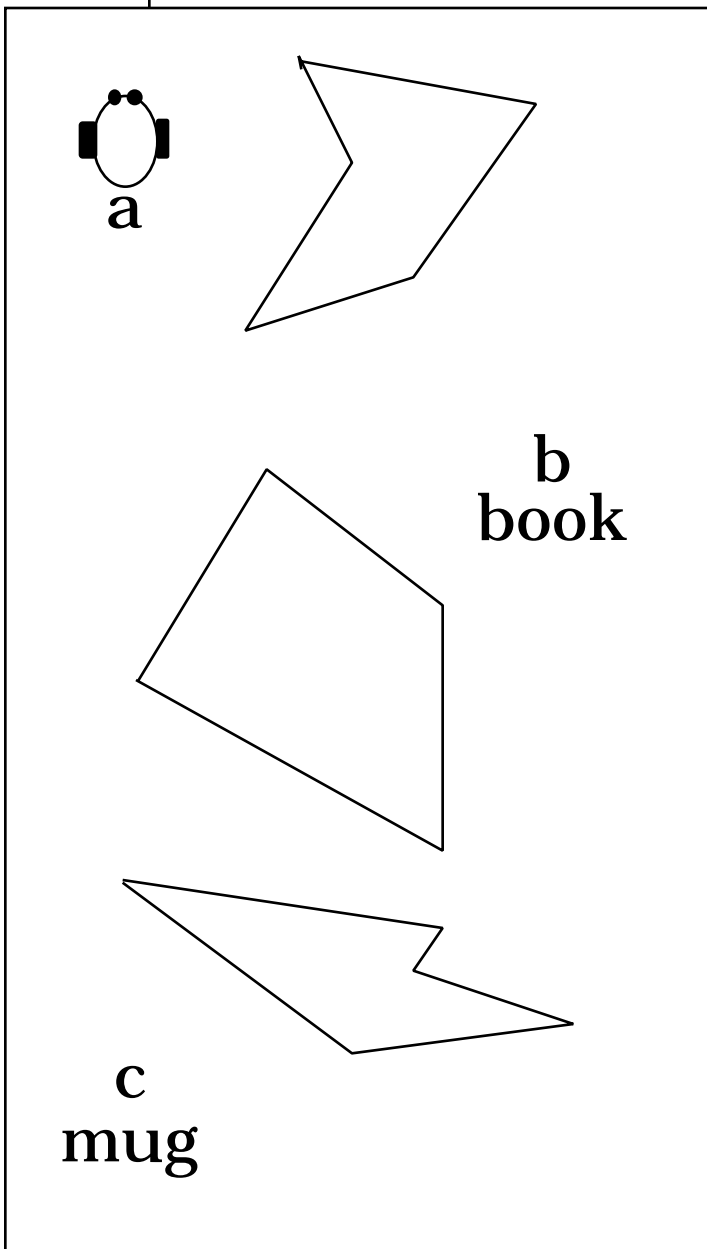
# A Different Structure for Acting



Hertzberg, Jaeger, Morignot, Zimmer:  
A Framework for Plan Execution in  
Behavior-Based Robots. 1998

Jaeger: The Dual-Dynamics design scheme  
for behavior-based robotics. 1996.  
Jaeger & Christaller: Dual Dynamics:  
Designing behavior systems for  
autonomous robots. In: Artificial Life and  
Robotics. 1998.

# The „Application“ Example



## Behavior 1: approach<sub>a</sub>

### Target dynamics

$$\dot{m}_l = k_1 \left( \frac{1}{2} + \frac{1}{2} o_l - \frac{1}{2} o_r - \frac{1}{2} a - m_l \right) + k_2 (o_l + o_r)(0 - m_l) + k_3 a (0 - m_l)$$

$\dot{m}_r$  correspondingly

### Activation dynamics

$$\dot{a} = k_4 \left( 1 - \left( i_l + i_r \right) - a \right) + k_5 a (0 - a) + \text{noise} + \text{operator coupling terms}$$

**All behaviors**

approach <sub>a</sub>	approach <sub>b</sub>	approach <sub>c</sub>	roam
gather <sub>book</sub>	gather <sub>mug</sub>	dump <sub>book</sub>	dump <sub>mug</sub>

# Operators

## **(operator GOTO**

**(params** (<l1> location) (<l2> location))  
**(preconds** (at robot <l1>))  
**(effects** (del at robot <l1>) (at robot <l2>)))

## **(operator LOAD**

**(params** (<o> object) (<l> location))  
**(preconds** (at <o> <l>) (at robot <l>))  
**(effects** (del at <o> <l>) (has-robot <o>)))

## **(operator UNLOAD**

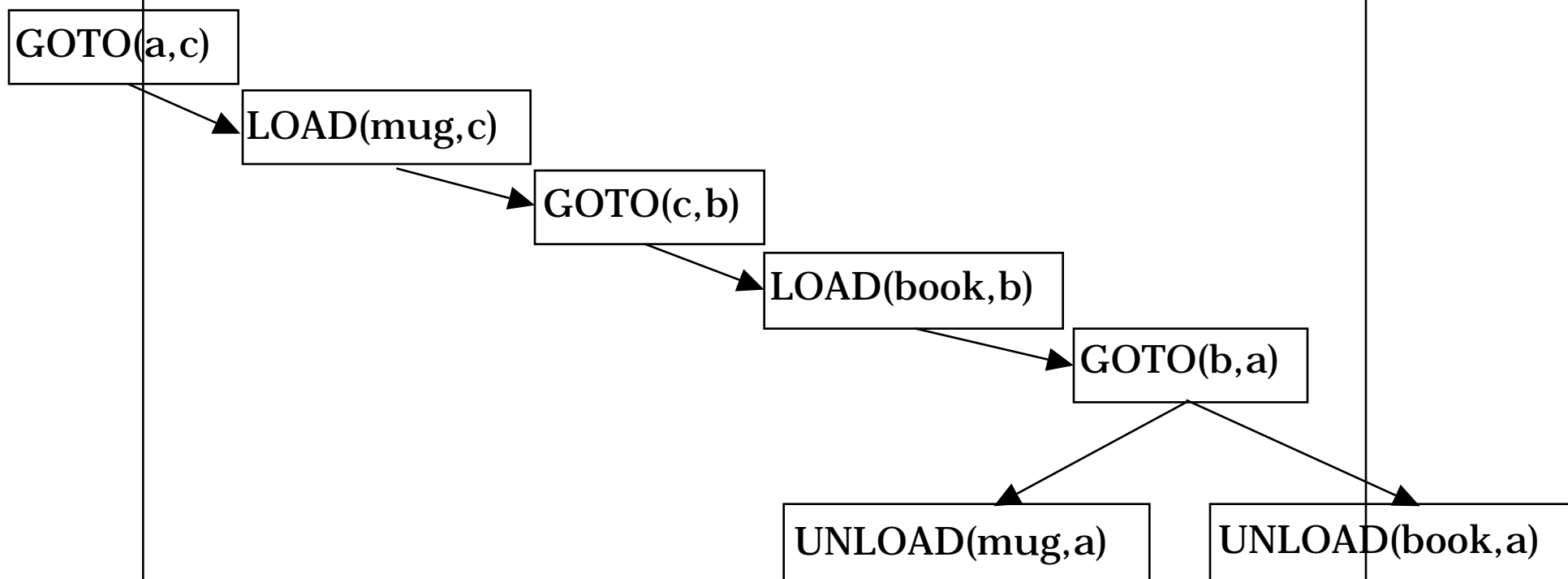
**(params** (<o> object) (<l> location))  
**(preconds** (has-robot <o>) (at robot <l>))  
**(effects** (at <o> <l>) (del has-robot <o>)))

# Problem and Solution Plan

(mug object) (book object) (a location) (b location) (c location)

**(preconds** (at mug c) (at book b) (at robot a))

**(effects** (at mug a) (at book a))



# Symbol $\rightarrow$ Dynamics

## Operator coupling term (OCT)

for operator OP in behavior j

$$\dot{x}_j = \dots + S_{OP} C_{OP}^j (Z - x_j) \quad \text{where } Z \in \{0, 1\}$$

## Example: OCTs for GOTO(L,b)

2: approach  $S_{GOTO(L,b)} C_{GOTO(L,b)}^2 (1 - x_2)$

4: roam  $S_{GOTO(L,b)} C_{GOTO(L,b)}^4 (1 - x_4)$

all others  $S_{GOTO(L,b)} C_{GOTO(L,b)}^i (0 - x_i)$

## Symbol ← Dynamics

### has-robot(book)

$$t. [ \text{has\_robot}(\text{book})(t) = 1 \quad t. [t > t_0 \quad \neg \text{has\_robot}(\text{book})(t) \ll 1 ] ]$$

### at(robot,a)

$$t_1, t_2. \quad t_1 < t_2 \quad t_2 - t_1 < \epsilon$$

$$\text{at}(\text{robot}, a)(t_1) = 1 \quad \text{at}(\text{robot}, a)(t_2) = 0$$

$$t, i. [ t_2 < t \quad \text{at}(\text{robot}, a)(t) = 1 \quad i \in \{2, 3, 4\} ]$$

$$l. \quad t \in [t_1, t_2]. \quad S_{\text{GOTO}(l, a)}(t) = 1$$

## **The Role of Planning in Robots**

- **Plans guide action. They don't enslave it.**
- **Realizing plans by action is complex.**  
**Planning itself need not be.**
- **Planning concurs action.**  
**None is superordinate or subordinate.**
- **Perception is action. So is planning.**
- **Planning, action, and learning must coexist.**

# Artificial and Natural Intelligence

- AI is the enterprise of constructing an intelligent artifact.

...

So what is intelligence? ...

There is something else outside the scope of AI that people are good at. People are good at being people. ...

AI is the enterprise of constructing a physical-symbol system that can reliably pass the Turing test. Matt Ginsburg: Essentials of AI. 1993, p. 3-17

## Why Does It Pay Off To Be Intelligent?

- We suggest that vervets and other primates make good primatologists. They observe social interactions, recognize the relations that exist among others, and classify relationships into types. ...  
(Primate intelligence) originally evolved to solve social problems and was only later extended to problems outside the social domain. D.L. Cheney, R.M. Seyfarth: Précis of How monkeys see the world. Behavioral and Brain Sciences, 1992, Vol. 15, p. 135-182
- Empathy is the feeling that persons or objects arouse in us as projections of our feelings and thoughts. It is evident when "I and you" becomes "I am you", or at least "I might be you". H. Spiro: What is empathy and can it be taught. Annals of Internal Medicine, 1992, Vol. 116, pp.843-846
- In human conversations about 60% of time is spent gossiping about relationships and personal experiences. Language may accordingly have evolved to allow individuals to learn about the behavioral characteristics of their group members more rapidly than was feasible by direct observation alone. R.I.M. Dunbar: Coevolution of neocortical size, group size and language in humans. Behavioral and Brain Sciences, 1993, Vol. 16, pp. 681-735

# Rehearsal: By What Means Intelligence Take Off the Ground

- And one of the deepest, one of the most general functions of living organisms is to look ahead, to provide future as Paul Valery put it. Francois Jacob: The Possible and the Actual. 1982
- Anticipation and rehearsal allows for
  - self-teaching and self-stimulating learning (imagination, dreams)
  - learning without any (given) goal, triggered by nearly any stimuli
  - providing a tested library of (parts of) movements just in case a real situation needs it
  - striving for mastery
- Life-long process of
  - learning
  - increasing of performance
- Using and constructing models of the world, of others, and of oneself
- Insight without eyes, photos or movies

# Conclusion

- There is nothing more practical than a good theory
- There is nothing more stimulating than a practical problem
- Science poses the basic questions and gives you the methodological means BUT the application gives you the course to steer
- Advice for Cognitive Roboticists
  - Oyster Principle
  - Bootstrap Principle
  - Scaling-Up Principle
- Thanks to:
  - Kerstin Dautenhahn (Reading), Brian Duffy (Belfast), Christian Haider (Industry), Joachim Hertzberg, Herbert Jaeger, Frank Kirchner, Uli Licht, David McFarland (Oxford), Raphael Nunez (Berkeley), Franco di Primio, Stefan Reimann, Erich Rome, Uwe Schnepf (Industry), Luc Steels (Paris), Uwe Zimmer