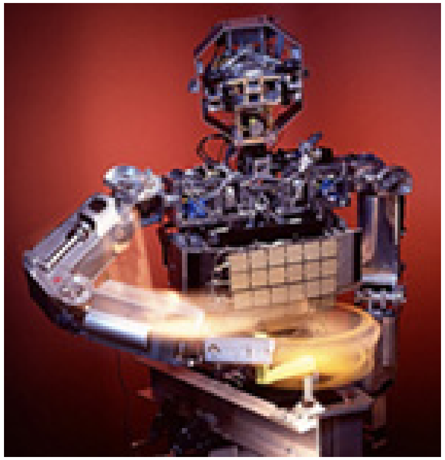
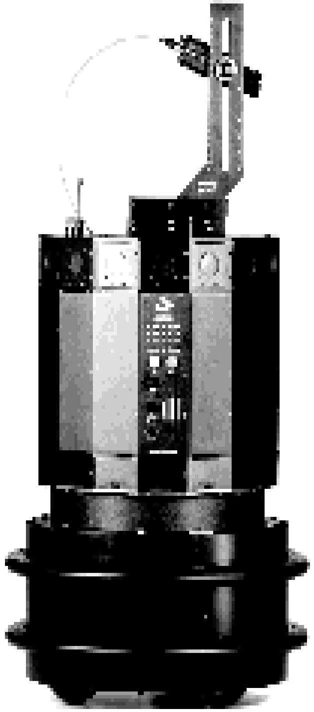
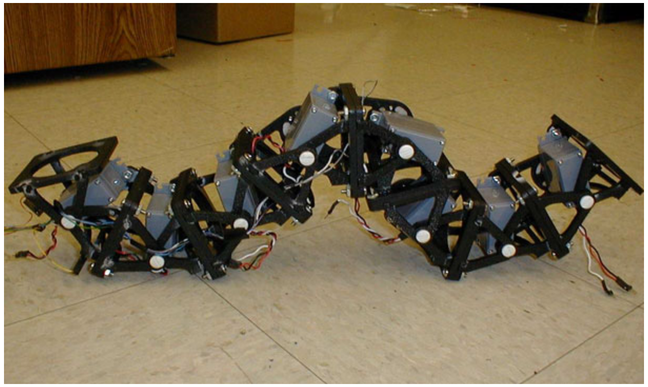
Abbreviated Modern History of Intelligent Mobile Robotics

August 26, 2014







Reading Assignment

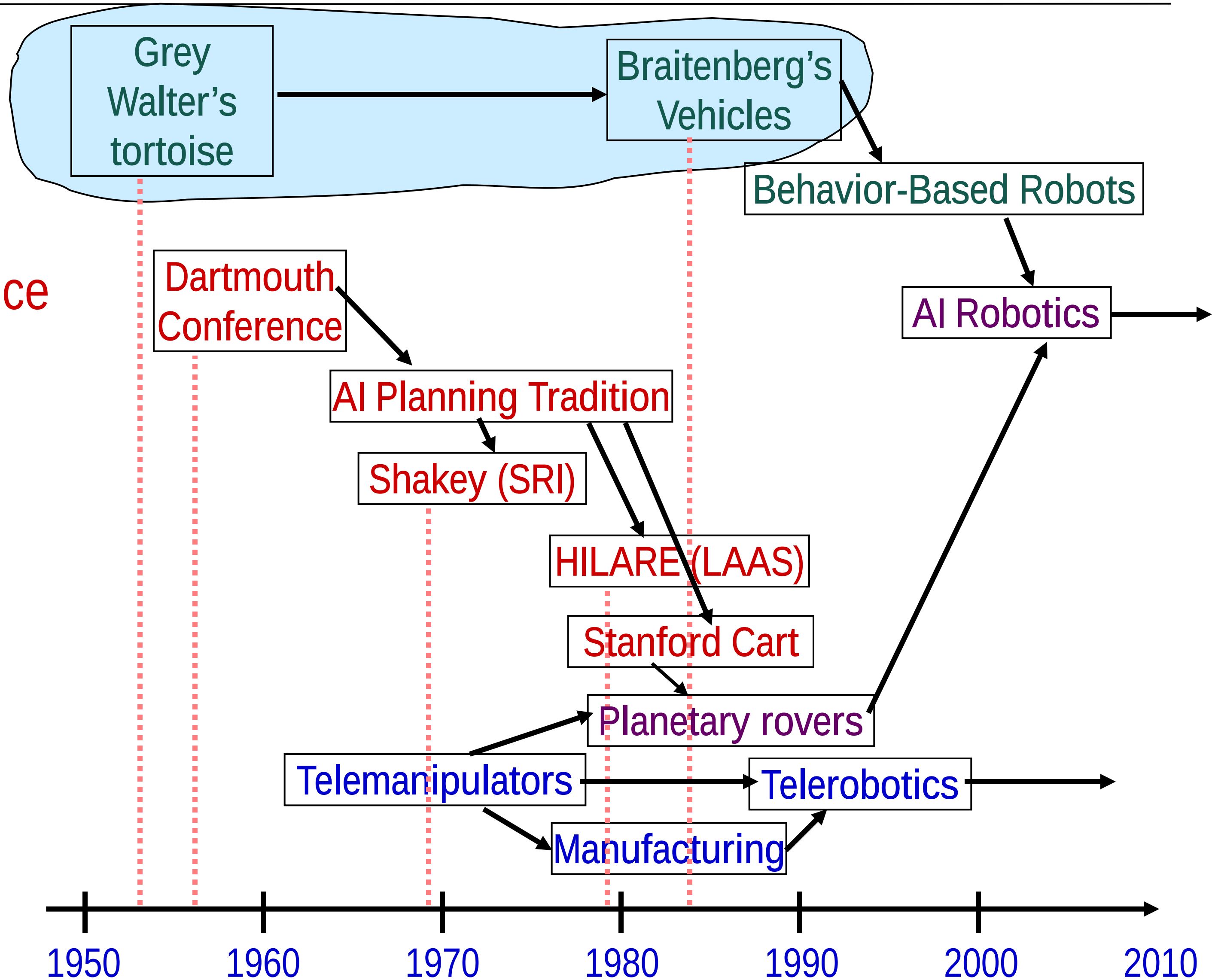
- Read Chapter 2 of Siegwart text (Locomotion)
  - We'll begin studying that material on Thursday

Objectives

- Understand historical precursors to intelligent robotics:
  - Cybernetics
  - Artificial Intelligence
  - Robotics
- Become familiar with key milestones in development of intelligent robotics
- Understand overall approaches to robotic control taken by historical precursors

Historical Precursors to Today's Intelligent Robotics

- Cybernetics
- Artificial Intelligence
- Robotics



Cybernetics

- Cybernetics is combination of:
  - Control theory
  - Information science
  - Biology
- Seeks to explain control principles in both animals and machines
- Uses mathematics of feedback control systems to express natural behavior
- Emphasis is on *situatedness* -- strong two-way coupling between organism and its environment
- Leader of cybernetics field: Norbert Wiener in late 1940s

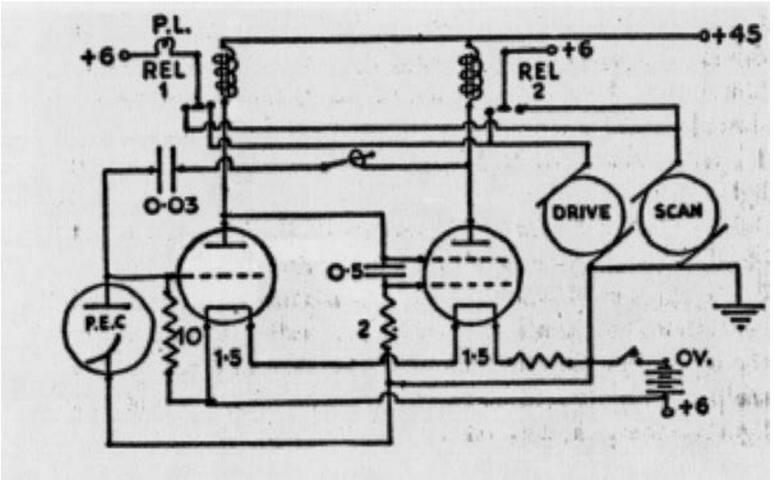
W. Grey Walter

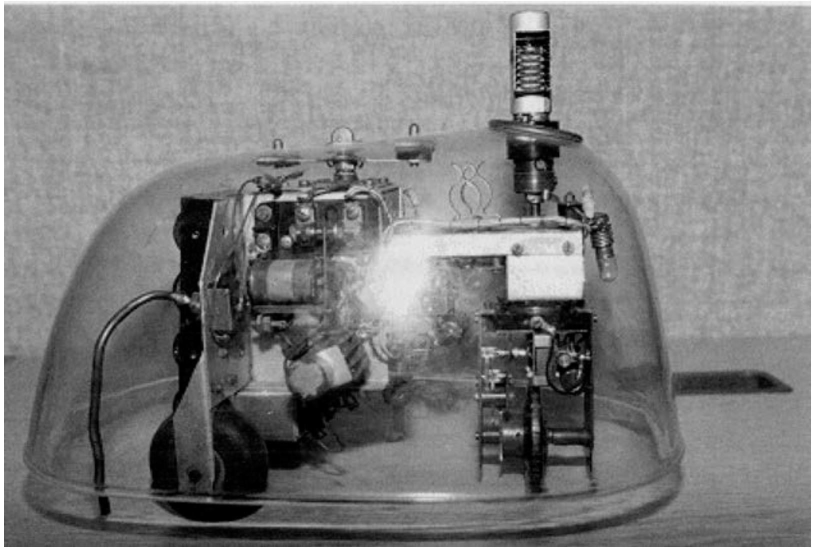
- Born in Kansas City in 1910, but raised in Cambridge, England
- Did work in 1920s with EEG

- Showed that certain patterns indicated person is learning
- Led to work in artificial intelligence and robotics

W. Grey Walter and one of his robots

Grey Walter's *Machina Speculatrix*, or Tortoise (1953)





- Sensors:
  - Photocell
  - Contact
- Actuators:
  - Steering motor on wheel
  - Driving motor on wheel

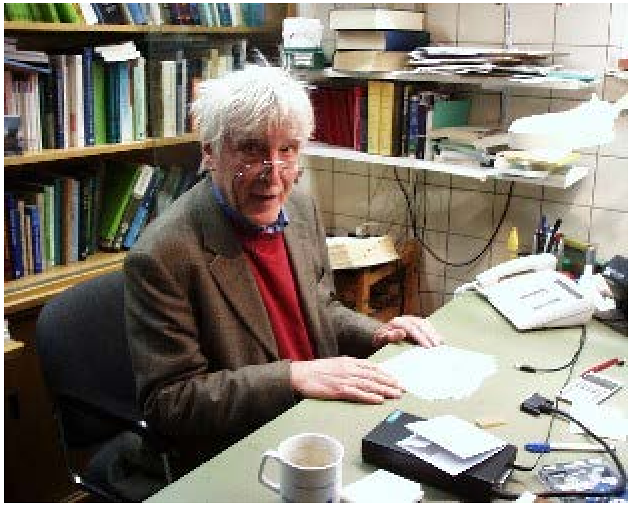
- Behaviors of tortoise:
  - Seeking light
  - Head toward weak light
  - Back away from bright light
  - Turn and push (for obstacle avoidance)
  - Recharge battery

Principles Learned from Walter's Tortoise

- Parsimony: simple is better
- Exploration or speculation: constant motion motion to avoid traps
- Attraction (positive tropism): move towards positive stimuli
- Aversion (negative tropism): move away from negative stimuli
- Discernment: distinguish between productive and unproductive behavior

Braitenberg's Vehicles (1984)

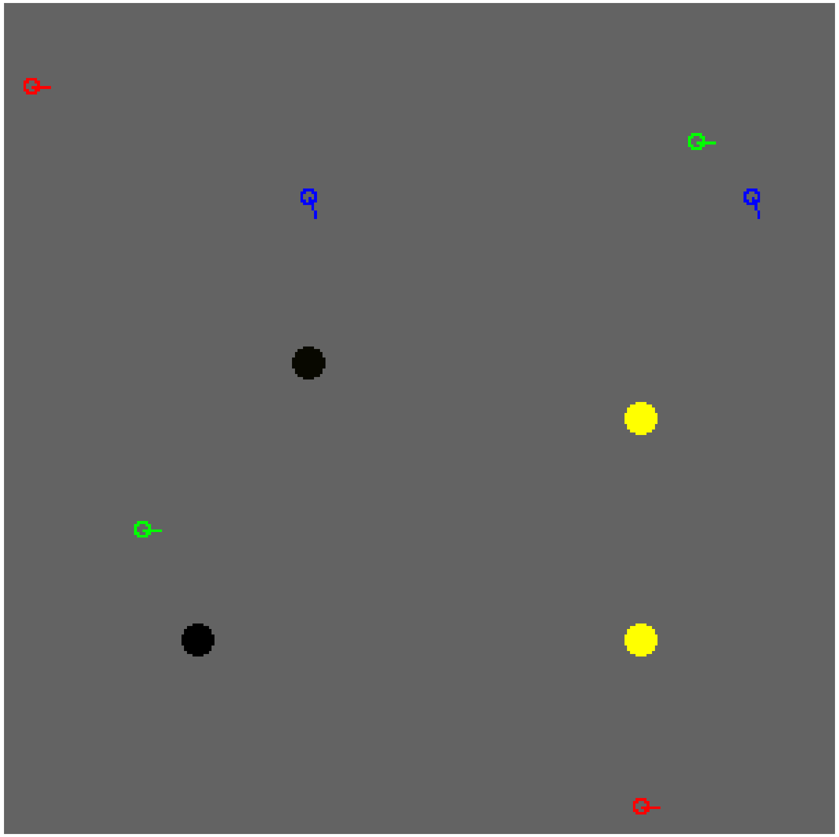
- Took perspective of psychologist
- Created wide range of vehicles
- Vehicles used inhibitory and excitatory influences
- Direct coupling of sensors to motors
- Exhibited behavioral characteristics that appeared to be:
  - Cowardice
  - Aggression
  - Love
  - (Etc.)



Valentino Braitenberg
Former Director
Max Plank Institute for Biological Cybernetics, Germany

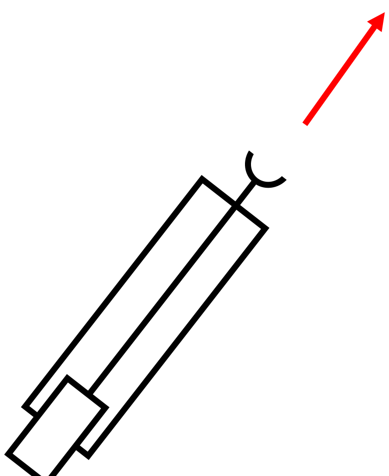
What behaviors do you see?

- (Movie of some of Braitenberg's vehicles)



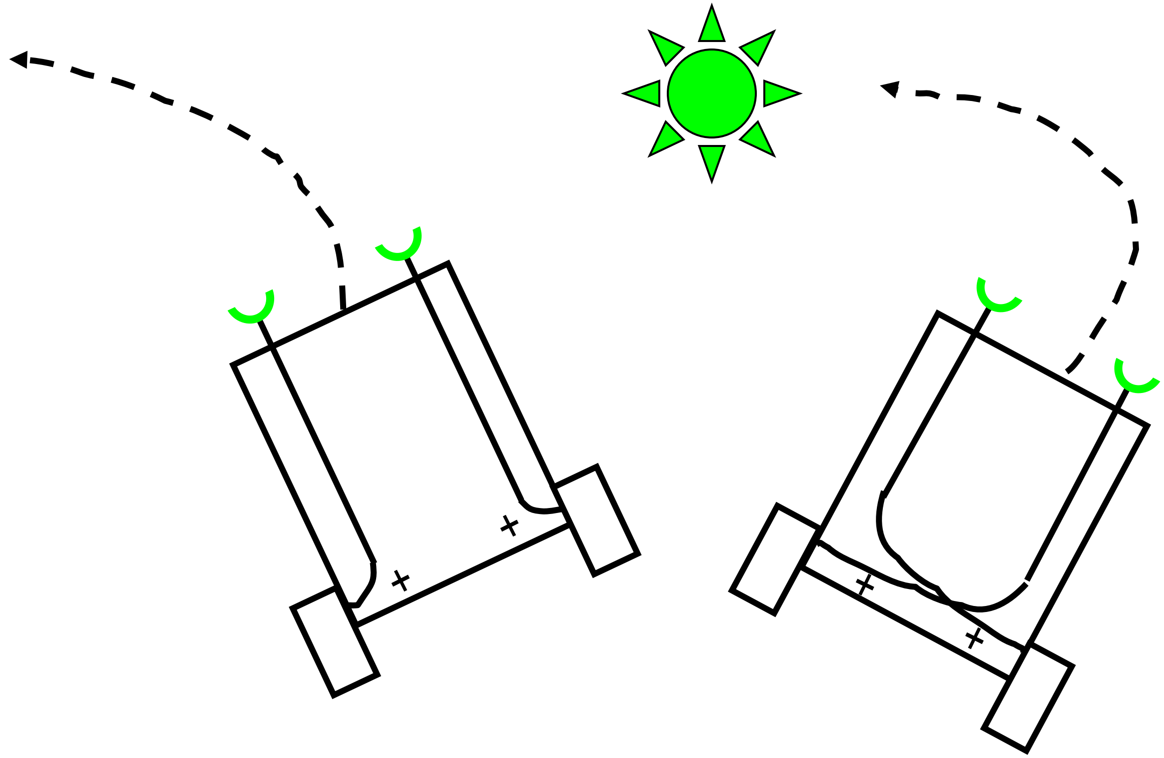
Braitenburg Vehicle 1: "Getting Around"

- Single motor, single sensor
- Motion always forward
- Speed controlled by sensor
- Environmental perturbations produce direction changes



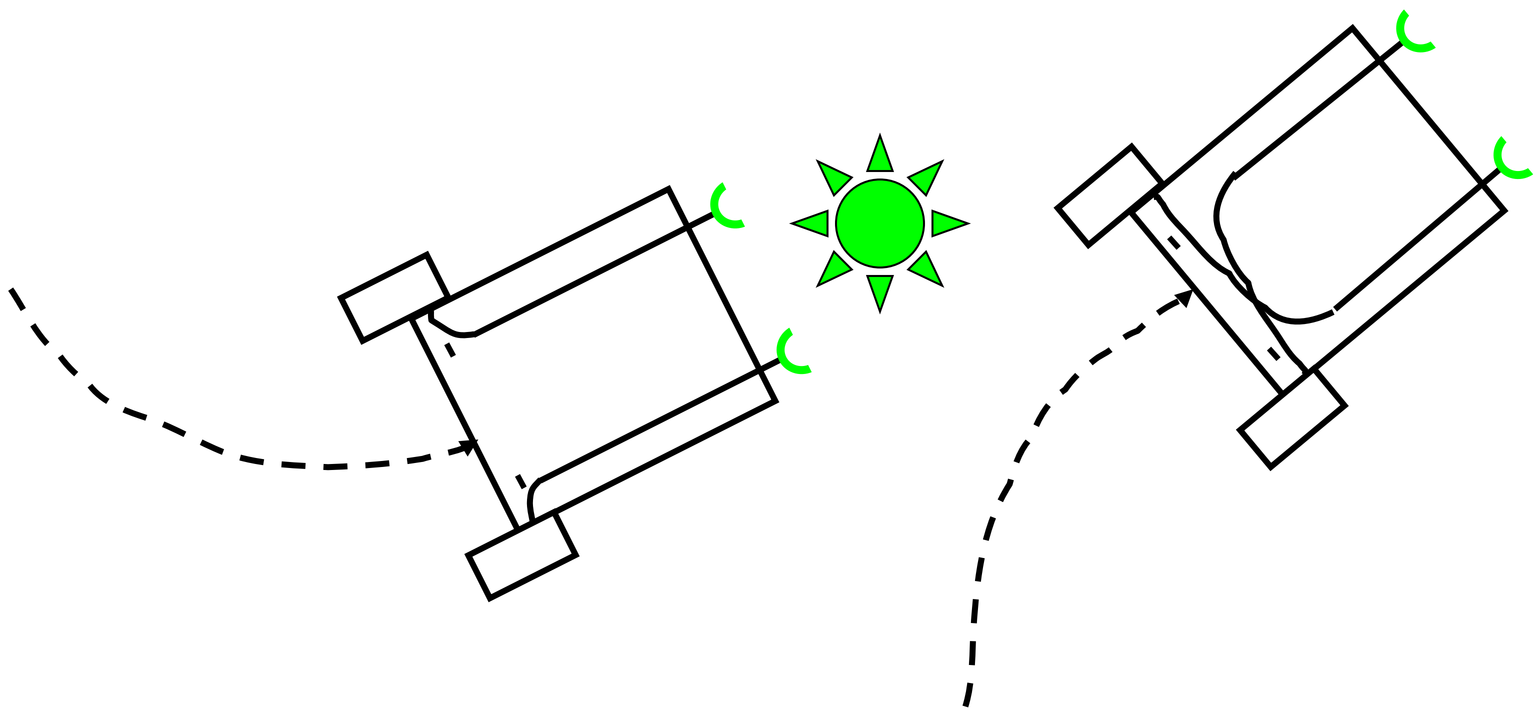
Braitenburg Vehicle 2: "Fear and Aggression"

- Two motors, two sensors
- One configuration: light aversive ("fear")
- Second configuration: light attractive ("aggression")



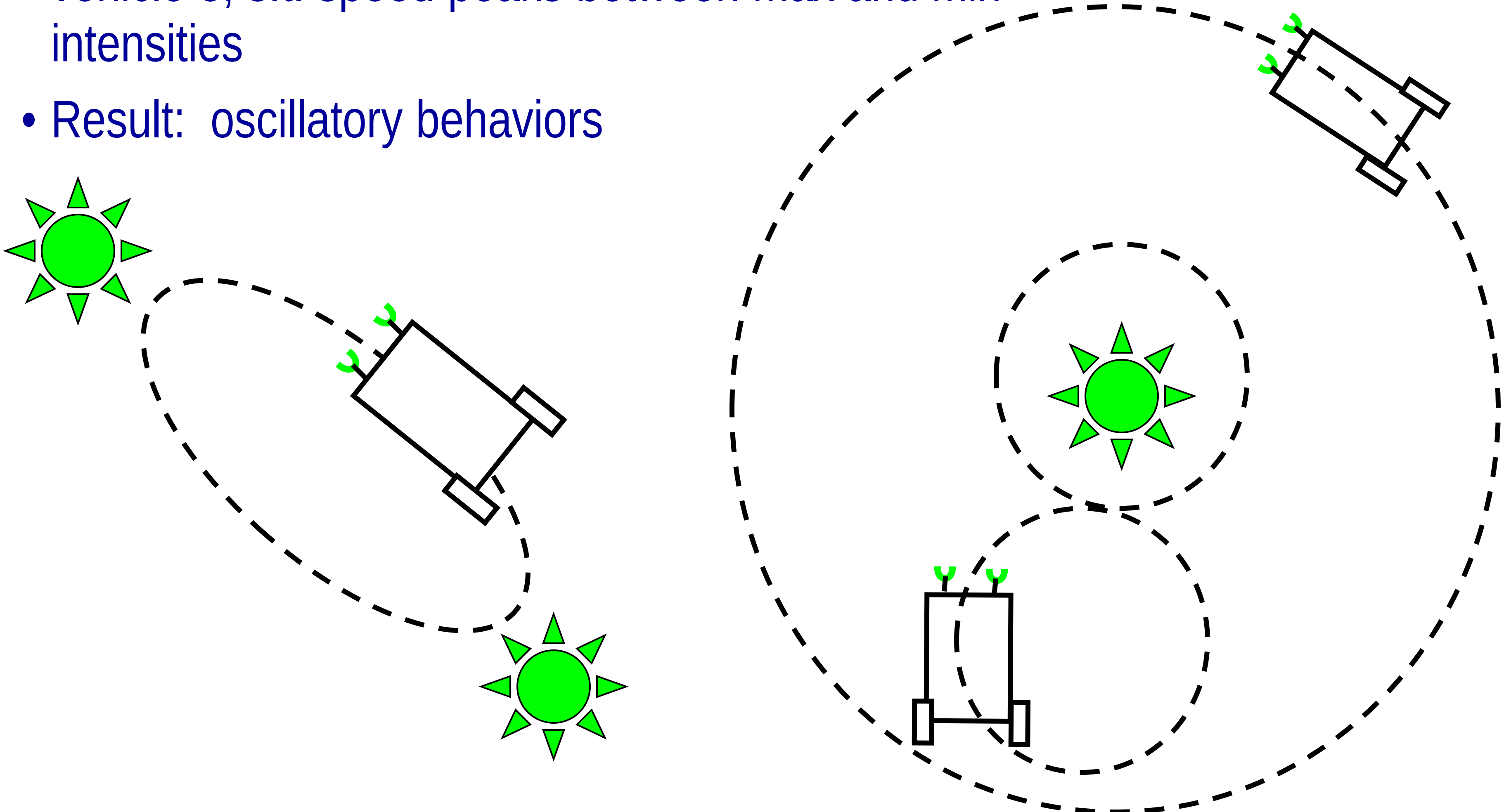
Braitenburg Vehicle 3: "Love and Exploration"

- Two motors, two sensors
- Same as vehicle 2, but with inhibitory connections
- One configuration: approaches and stops at strong light ("love")
- Second configuration: approaches light, but always exploring ("explorer")

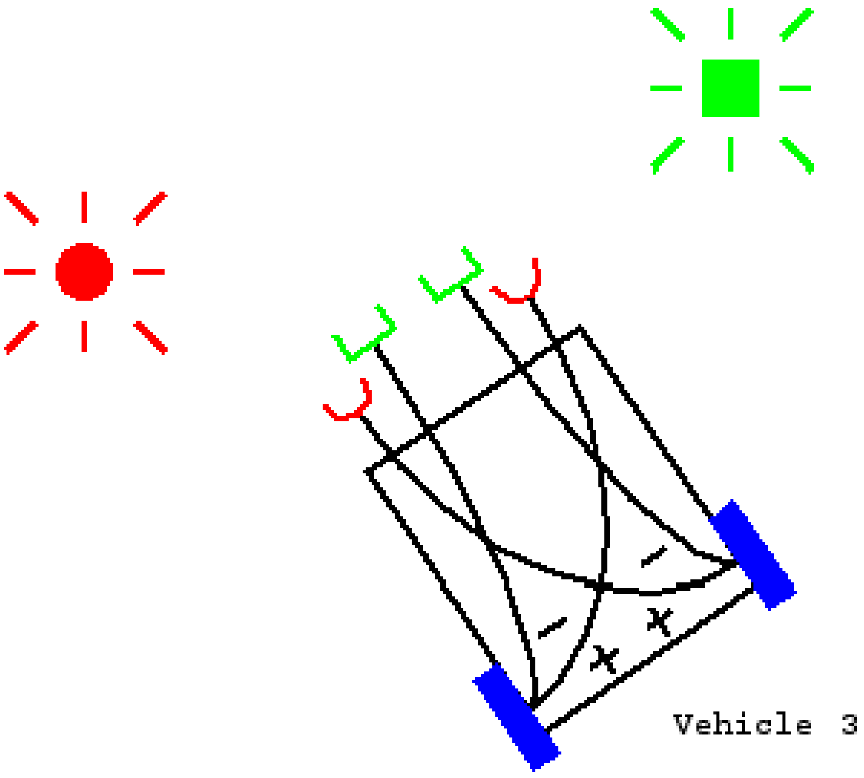


Braitenburg Vehicle 4: "Values and Special Tastes"

- Two motors, two sensors
- Add various non-linear speed dependencies to vehicle 3, s.t. speed peaks between max and min intensities
- Result: oscillatory behaviors



What would you expect of this vehicle?

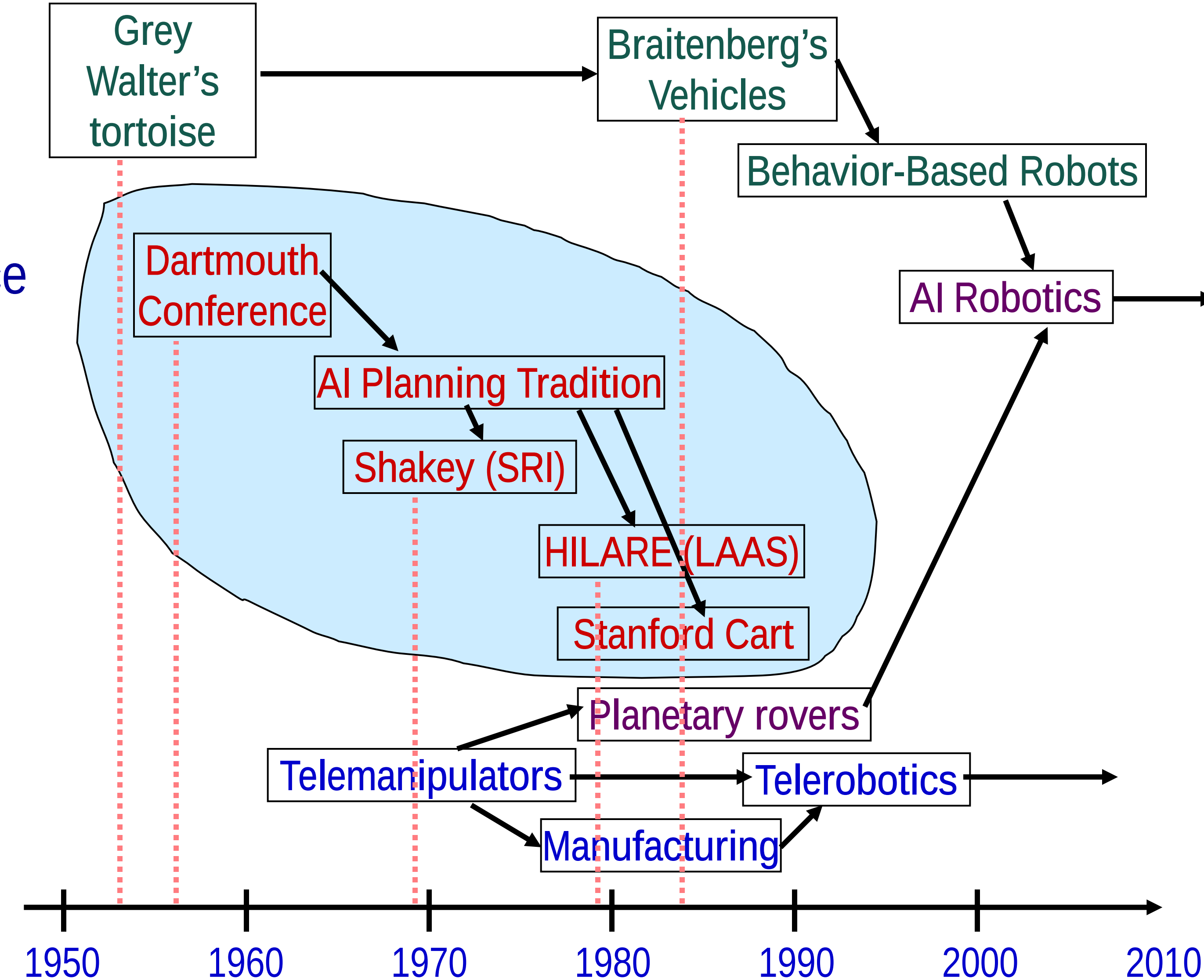


Summary of Braitenberg's Vehicles

- Systems are inflexible, non-reprogrammable
- However, vehicles are compelling in overt behavior
- Achieve seemingly complex behavior from simple sensorimotor transformations

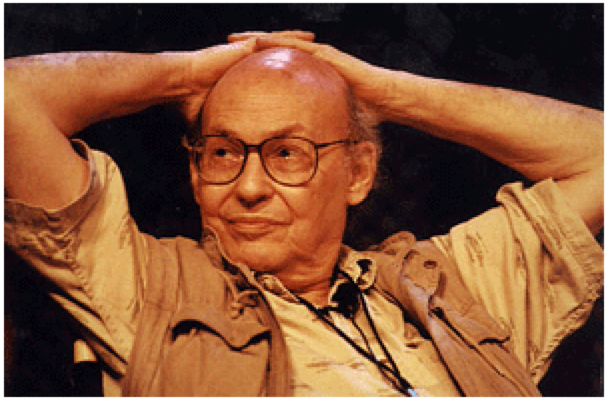
Historical Precursors to Today's Intelligent Robotics

- Cybernetics
- Artificial Intelligence
- Robotics



Artificial Intelligence (AI)

- Beginnings of AI: Dartmouth Summer Research Conference (1955)
- Original topics studied:
  - Language
  - Neural nets
  - Complexity theory
  - Self-improvement
  - Abstractions
  - Creativity



Marvin Minsky, MIT

- Marvin Minsky: *an intelligent machine "would tend to build up within itself an abstract model of the environment in which it is placed. If it were given a problem it could first explore solutions within the internal abstract model of the environment and then attempt external experiments."*

Early AI Roots Strongly Influenced Research

- Through mid-80’s, AI research strongly dependent upon:
  - Representational knowledge
  - Deliberative reasoning methods
  - Hierarchical organization

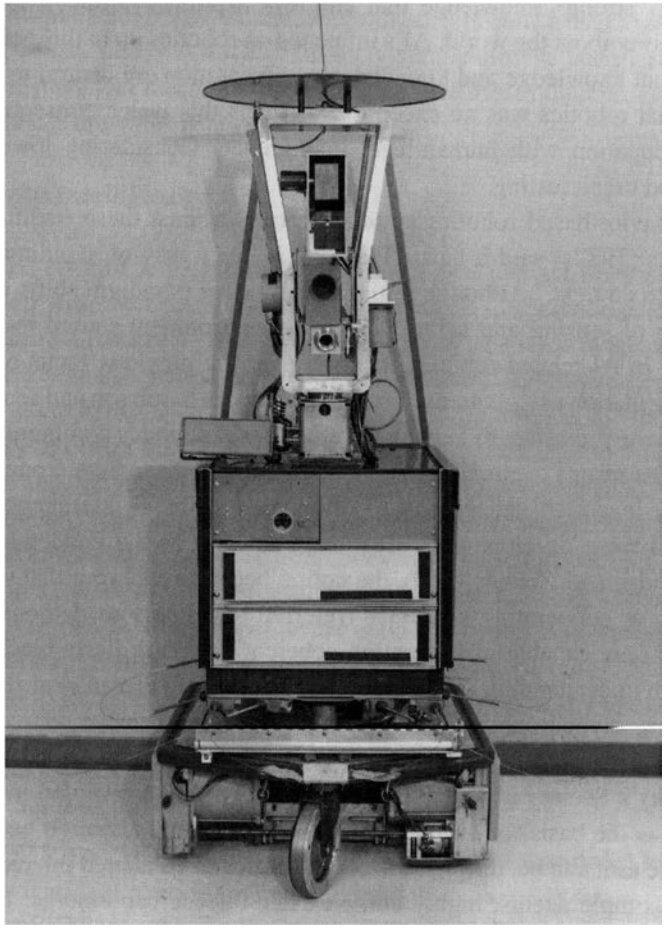
Classical AI Methodology

- Key characteristics:
  - The ability to represent hierarchical structure by abstraction
  - The use of “strong” knowledge using explicit symbolic representation
- Beliefs:
  - Knowledge and knowledge representation are central to intelligence
  - Robotics is no exception
- Focus:
  - Human-level intelligence
- Not of interest:
  - Animal-level intelligence

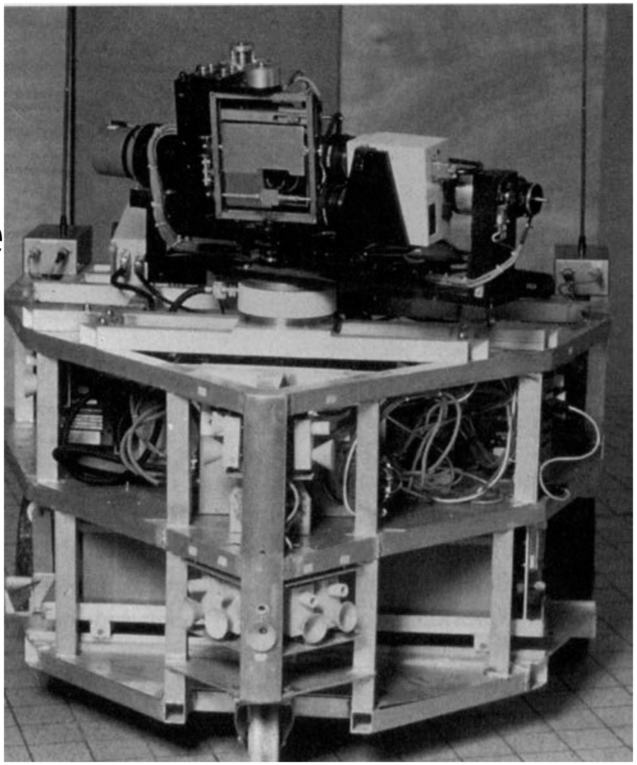
Early Robotics Development

Shakey (SRI), 1960's

- One of first mobile robots
- Sensors:
  - Vidicon TV camera
  - Optical range finder
  - Whisker bump sensors
- Environment: Office environment with specially colored and shaped objects
- STRIPS planner: developed for this system
  - Used world model to determine what
  - actions robot should take to achieve goals



Early Robotics Development (con't.)

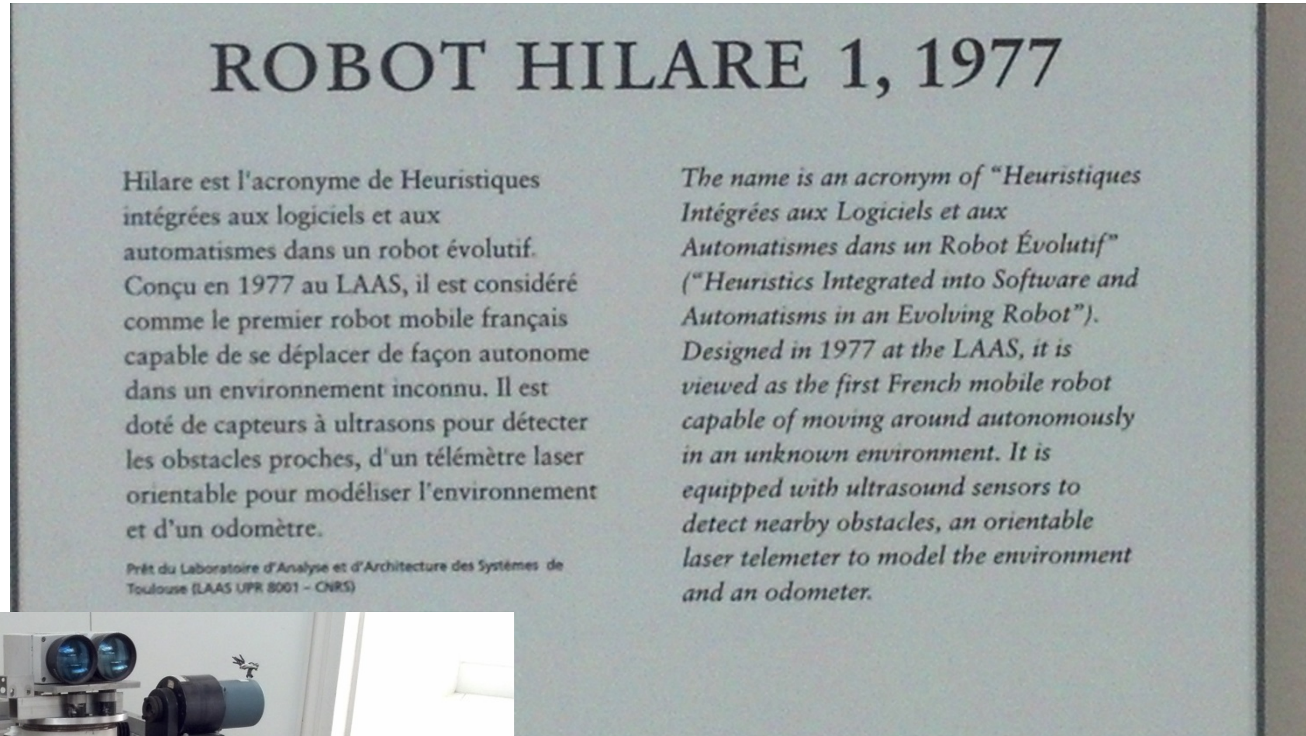


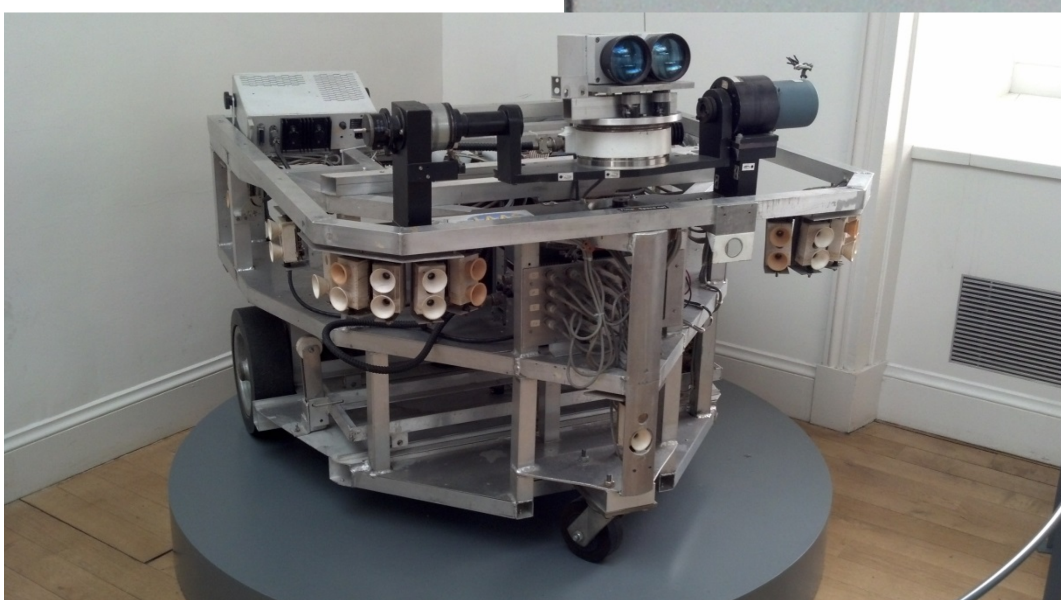
HILARE (LAAS-CNRS), 1970's

- Sensors: Video camera, 14 sonar, laser range finde
- Three wheels: two drive, one caster
- Weight: 400 kg
- World: smooth floors, office environment
- Planning:
  - Conducted in multi-level geometric representational space
- Use: for experimentation for over a decade

Early Robotics Development (con't.)

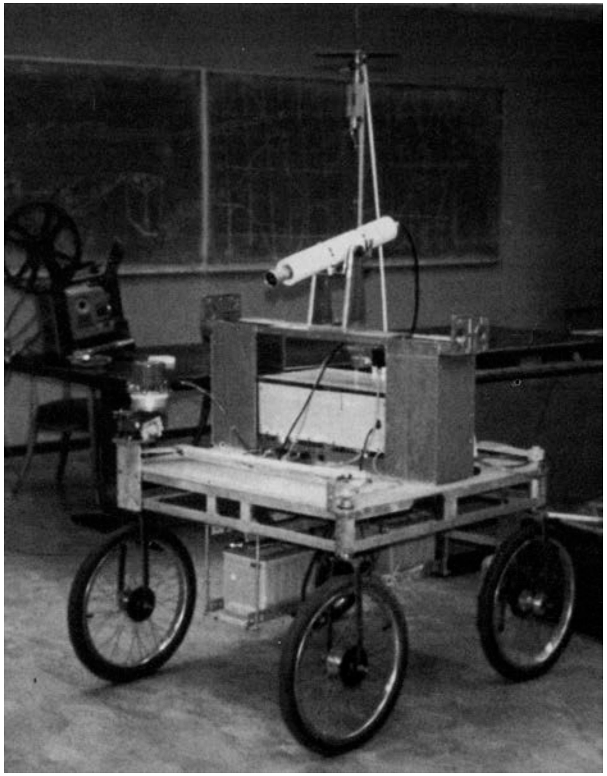
Hilare is now exhibited in Paris Museum of Arts and Meters (photos taken 2013)





Early Robotics Development (con't.)

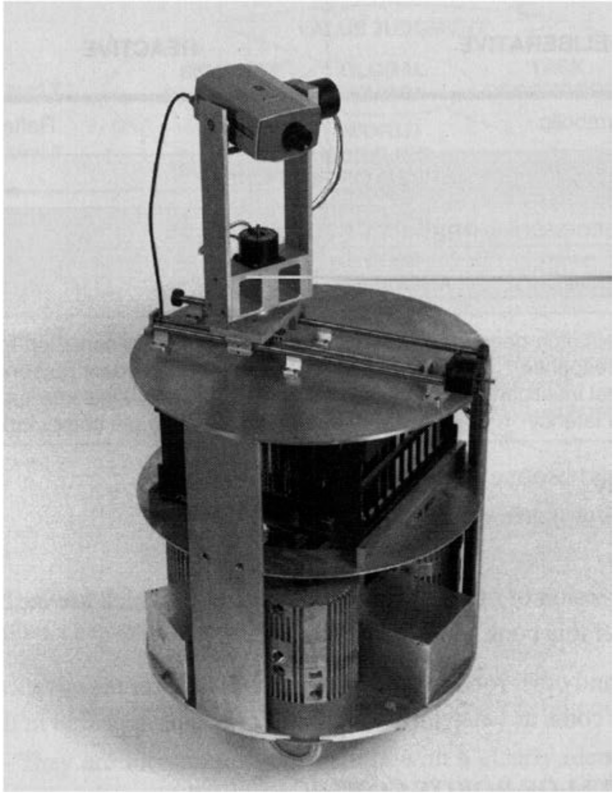
Stanford Cart, 1970's (Moravec)



- Sensors: Stereo vision used for navigation
- Speed: Very slow, moving at about 1 meter per 10-15 minutes
- Full run: 5 hours
- Obstacles: added to internal map as enclosing spheres
- Search: Used graph search algorithm to find shortest path
- Accomplishments: Successfully navigated complex 20-meter courses, visually avoiding obstacles

Early Robotics Development (con't.)

CMU Rover, 1980's



- Follow-on to Stanford Cart
- Sensors:
  - Camera mounted on pan/tilt
  - Infrared and sonar sensors
- Actuators: Three independently powered/steered wheels
- Accomplishments: Set stage for upcoming behavior-based robotics

Planning-Based Approach to Robot Control

- Job of planner: generate a goal to achieve, and then construct a plan to achieve it from the current state.
- Must define representations:
  - Representation of actions: programs that generate successor state descriptions
  - Representation of states: data structure describing current situation
  - Representation of goals: what is to be achieved
  - Representation of plans: solution is a sequence of actions

Typically: Use first-order logic and theorem proving to plan strategies from start state to goal

First Order Predicate Calculus in AI

- First order predicate calculus: formal language useful for making inferences and deductions
- Elementary components:
  - Predicate symbols (e.g., WRITES(), LIVES(), OWNS(), MARRIED())
  - Variable symbols (e.g., *x, y)*
  - Function symbols (e.g., *father(x)* returns the father of *x*)
  - Constant symbols (e.g., HOUSE-1, NERO, GEORGE-BUSH)
  - Connectives
    - and, or, negation, implies $\wedge, \vee, \neg, \Rightarrow$
  - Quantification
    - Universal $\forall x$
    - Existential $\exists x$
- NOTE: *First order* means quantification over predicates or functions not allowed

Use Rules of Inference, Unification to Prove Theorems

- Rules of inference:
  - P and $\sim P \vee Q$ resolves to Q (modus ponens)
  - $P \vee Q$ and $\sim P \vee Q$ resolves to Q
  - $P \vee Q$ and $\sim P \vee \sim Q$ resolves to $Q \vee \sim Q$ and $P \vee \sim P$
  - $\sim P$ and P resolves to Nil
  - Etc.

- Unification:
  - Finding substitutions of terms for variables to make expressions identical
  - Equivalent to symbolic pattern matching
    - E.g.: Add-List: ON(x,y) can be made equivalent to ON(A,B) through substitution and unification

Many AI Planners Developed From these Concepts

- Well-known AI Planners:
  - STRIPS (Fikes and Nilsson, 1971): theorem-proving system
  - ABSTRIPS (Sacerdoti, 1974): added hierarchy of abstractions
  - HACKER (Sussman, 1975): use library of procedures to plan
  - NOAH (Sacerdoti, 1975): problem decomposition and plan reordering

STRIPS-Based Approach to Robot Control

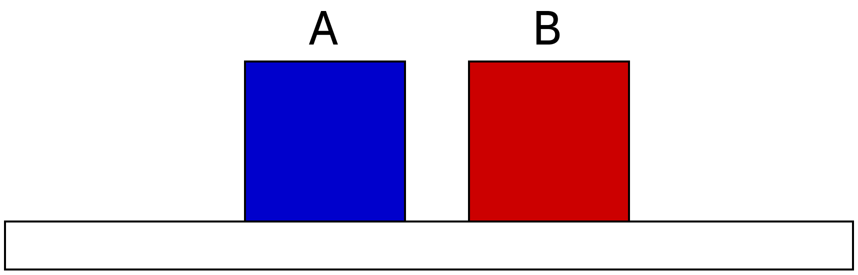
- Use first-order logic and theorem proving to plan strategies from start state to goal

- Define:
  - Goal State
  - Initial State
  - Operators

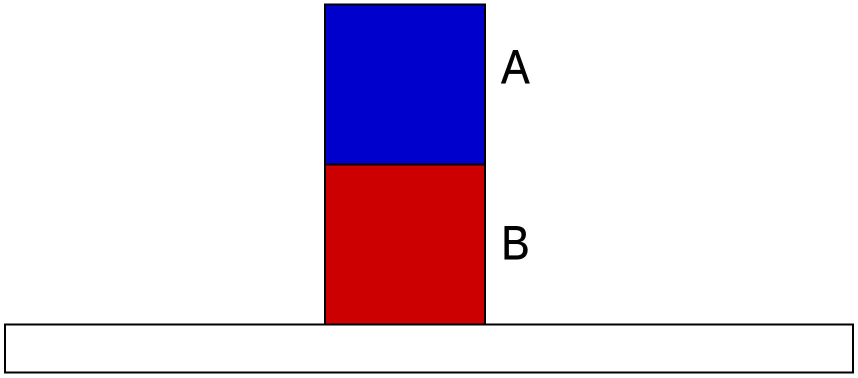
- STRIPS Operators have:
  - Action description
  - Preconditions
  - Effect:
    - Add-list
    - Delete-list

Simple Example of STRIPS-Style Planning

- Goal State: ON(A,B)
- Start state: ON(A, Table); ON(B, Table); EMPTYTOP(A); EMPTYTOP(B)
- Operator:
  - MOVE(x,y):
    - Preconditions: ON(x,Table); EMPTYTOP(y)
    - Add-List: ON(x,y)
    - Delete-List: EMPTYTOP(y); ON(x,Table)



Start State



Goal State

Shakey's STRIPS World

- Types of actions Shakey can make (at least in simulation):
  - Move from place to place:

Go(y):

PRECOND: At(Shakey,x)

In(x,r) $\wedge$ In (y,r)

On(Shakey,Floor)

EFFECT: At(y)

  - Push movable objects:

Push(b, x, y):

PRECOND: Pushable(b)

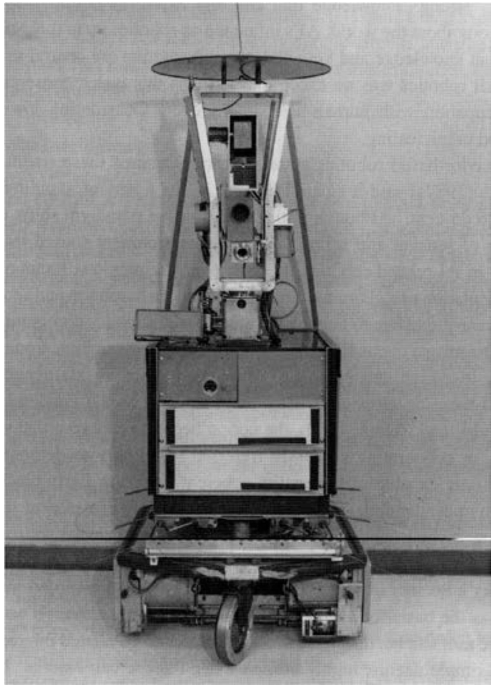
At(b,x)

At(Shakey,x)

In(x,r) $\wedge$ In (y,r)

On(Shakey,Floor)

EFFECT: At(b,y)



Shakey's STRIPS World (con't.)

- Types of actions Shakey can make (at least in simulation):
  - Climb onto rigid objects:

    Climb(b):

    PRECOND: Climbable(b)

    At(Shakey,x) $\wedge$ At(b,x)

    On(Shakey,Floor)

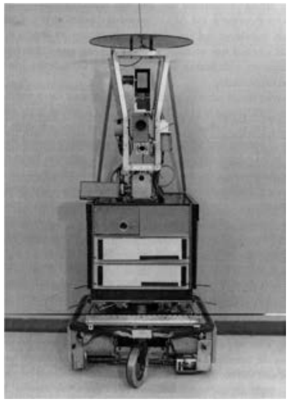
    EFFECT: On(Shakey,b)

  - Climb down from rigid objects:

    (etc.)

  - Turn light switches on and off:

    (etc.)



Challenges of AI and Planning Systems

- Closed world assumption: *Assumes that world model contains everything the robot needs to know: there can be no surprises*

- *Frame problem:* How to represent real-world situations in a manner that is computationally tractable

- *Open world assumption:* means that the closed world assumption cannot apply to the given domain

Historical Precursors to Today's Intelligent Robotics

- Cybernetics
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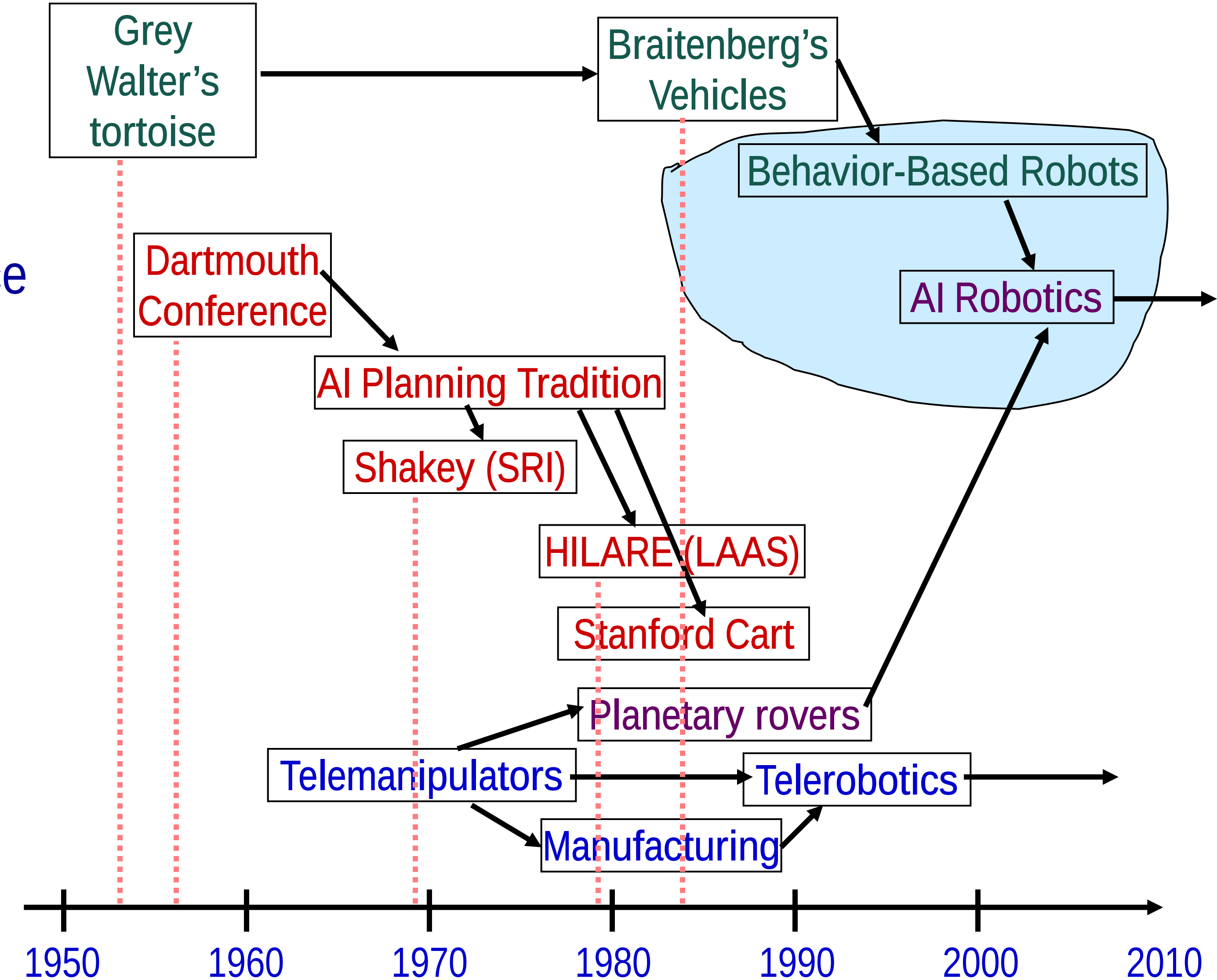
- Robotics



Behavior-Based Robotics' Response to Classical AI

- Reacted against classical AI

- Brooks (1987-1990):

  "Planning is just a way of avoiding figuring out what to do next"

  "Elephants don't play chess"

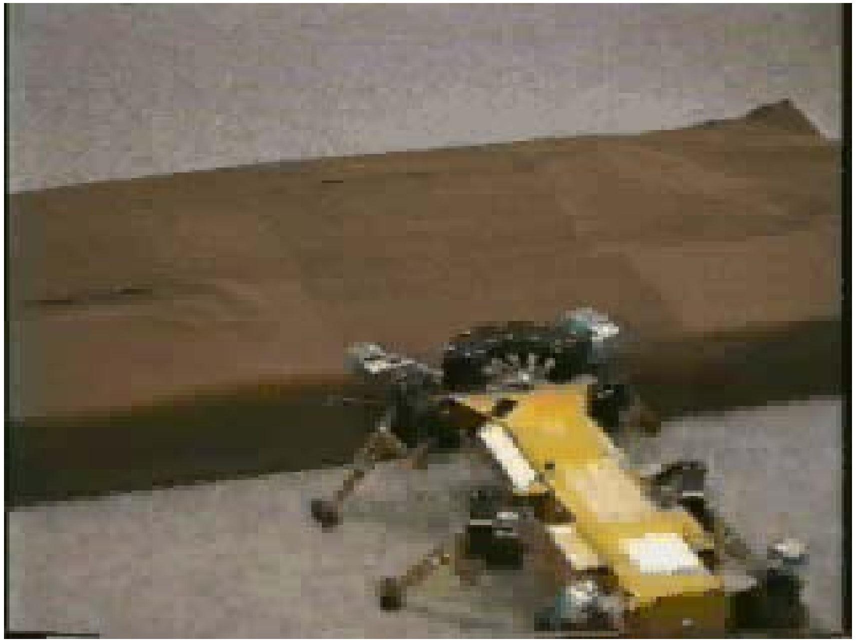
- Increased emphasis on:
  - Sensing and acting within environment

- Reduced emphasis on:
  - Knowledge representation
  - Planning

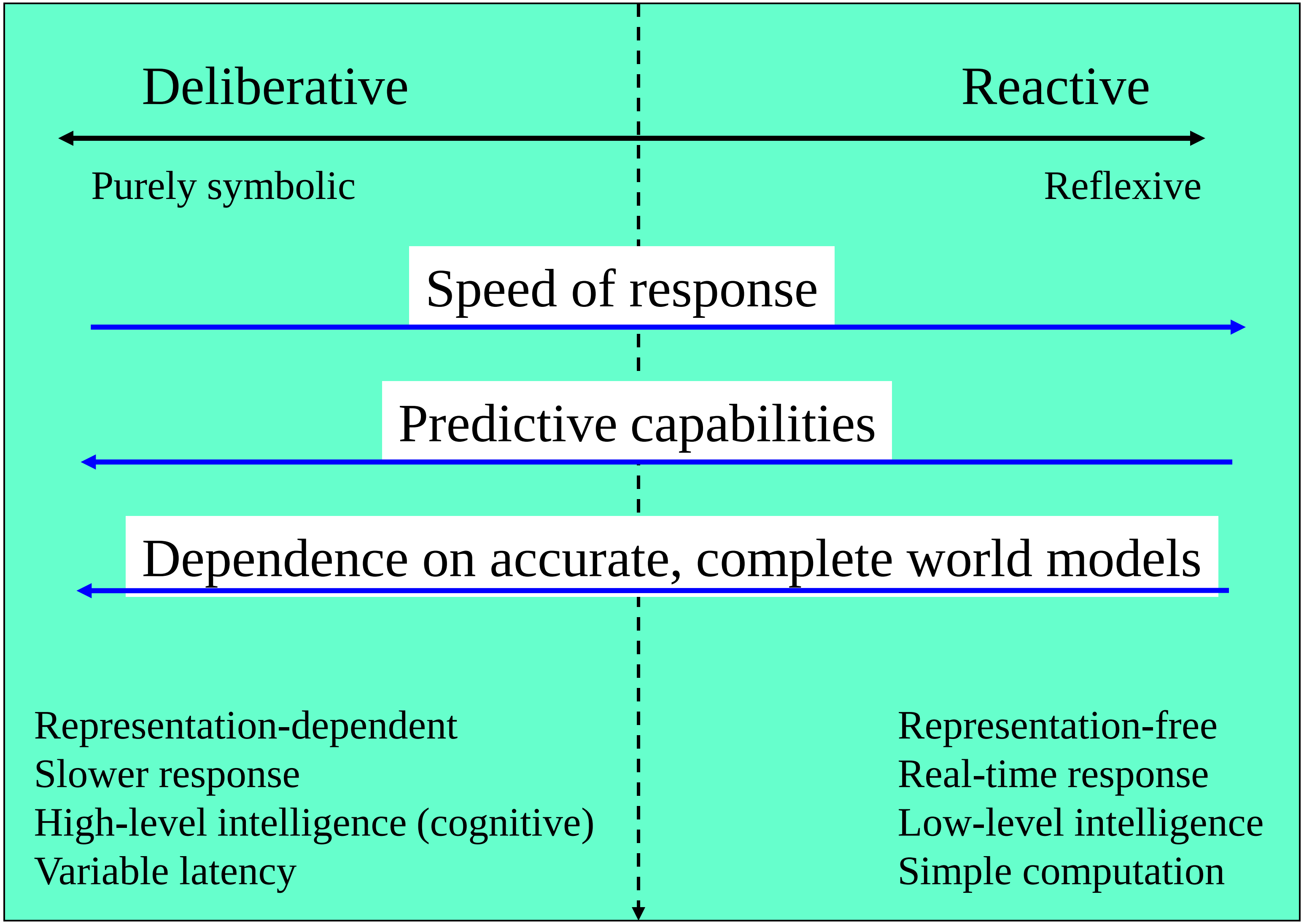
Rodney Brooks, MIT, with Cog

Now typically called "New AI"

Brooks' Genghis robot was first "Behavior-Based" robot



Wide Spectrum of Robot Control



Reactive Control

- Definition: a technique for tightly coupling perception and action, typically in the context of motor behaviors, to produce timely robotic response in dynamic and unstructured worlds.
- *Individual behavior*: a stimulus/response pair for a given environmental setting that is modulated by attention and determined by intention
- *Attention:* prioritizes tasks and focuses sensory resources; determined by current environmental context
- *Intention:* determines set of behaviors that should be active based on internal goals and objectives
- *Overt or emergent behavior*: the global behavior of robot as consequence of interaction of active individual behaviors
- *Reflexive behavior*: behavior generated by hardwired reactive behaviors with tight sensor-effector loop, using no world models

Key Issues of Behavior-Based Control

- Situatedness: robot operates in the real world
- Embodiment: robot has a physical presence (body)
- Emergence: Intelligence arises from interaction of robot with environment
- Grounding in reality: avoid symbol grounding problem
- Ecological dynamics: cannot characterize environment
- Scalability: Unknown whether behavior-based control will scale to human-level intelligence

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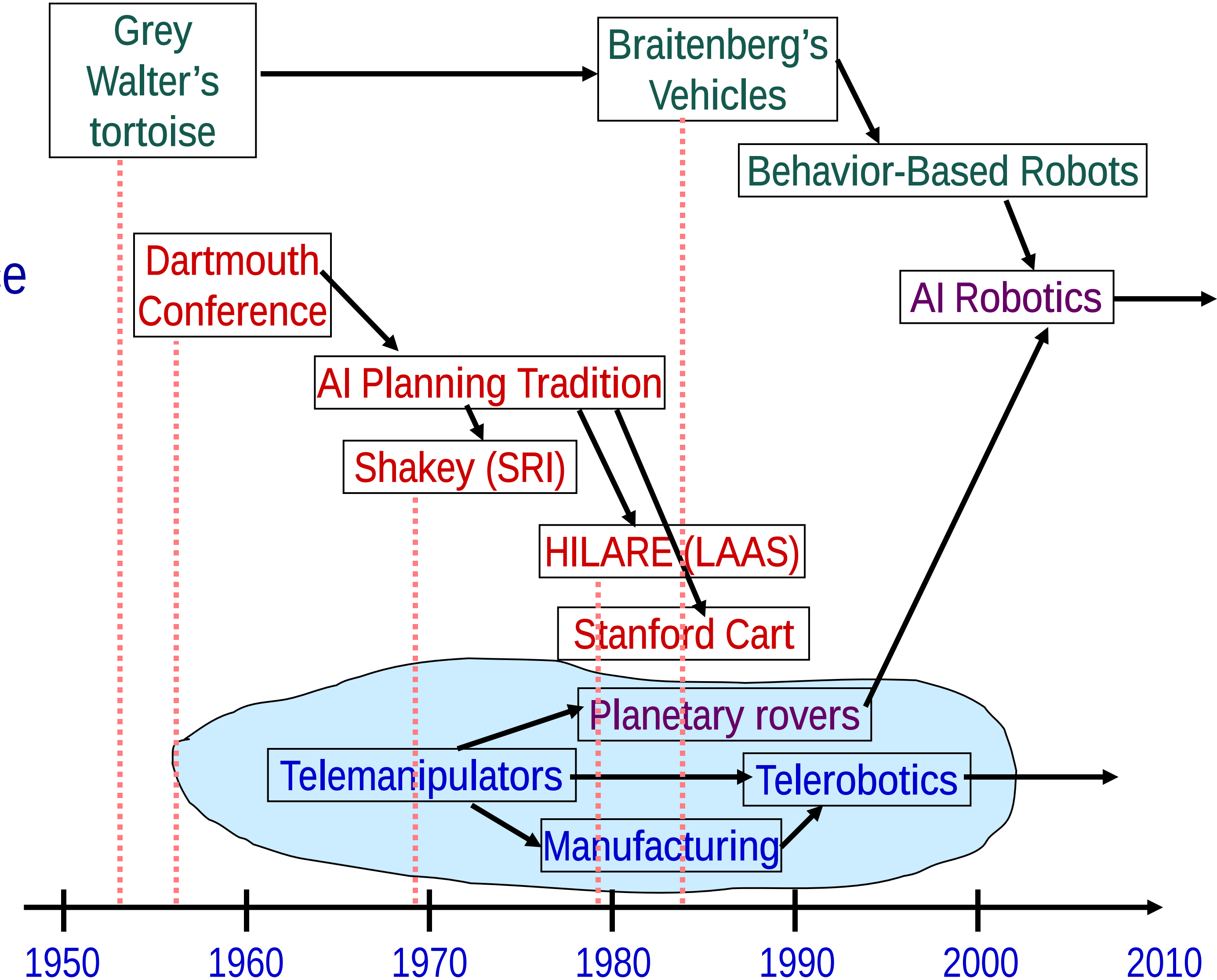
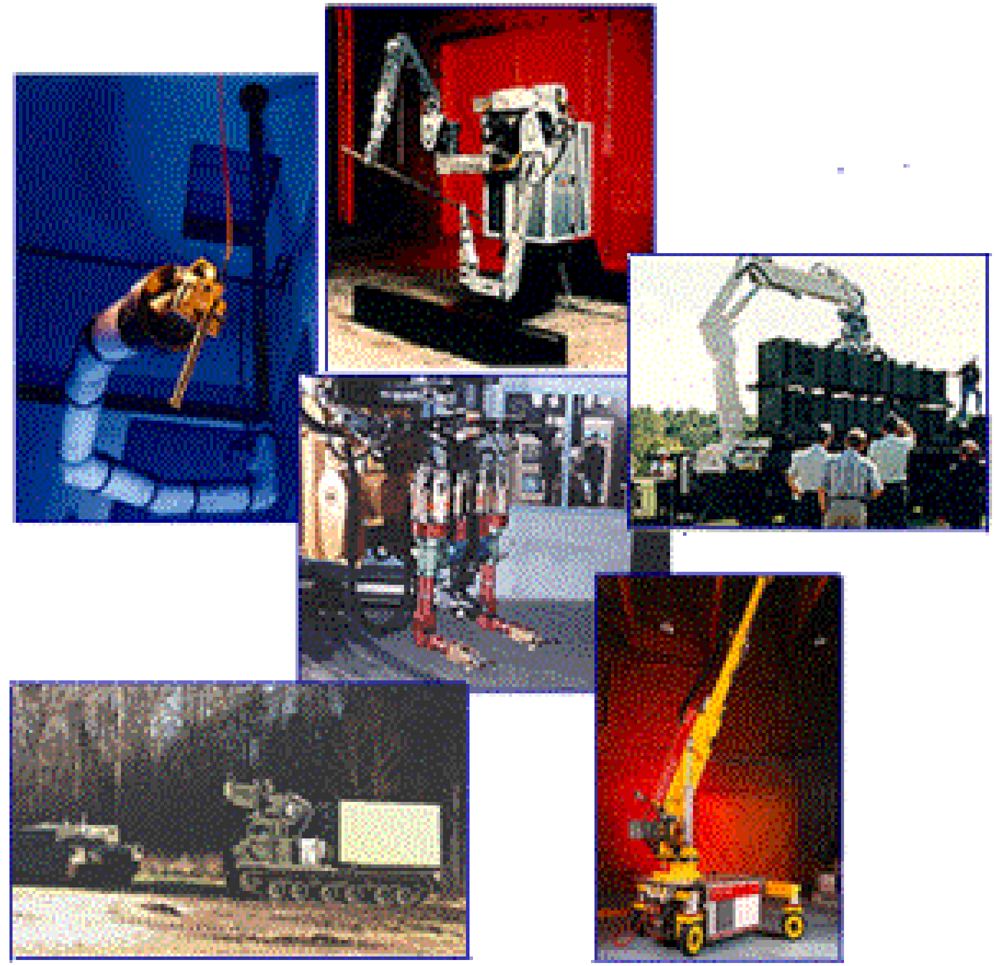


Telemanipulators and Telerobotics

- Teleoperation: human operator controls robot remotely through mechanical or electronic linkages
- Operator and robot:
  - Leader/follower relationship
  - Human leads, robot mimics human behaviors
- Issues include:
  - Force feedback
  - Operator telepresence
  - Supervisory control
- Challenges:
  - Operator overload
  - Cognitive fatigue
  - Simulator sickness



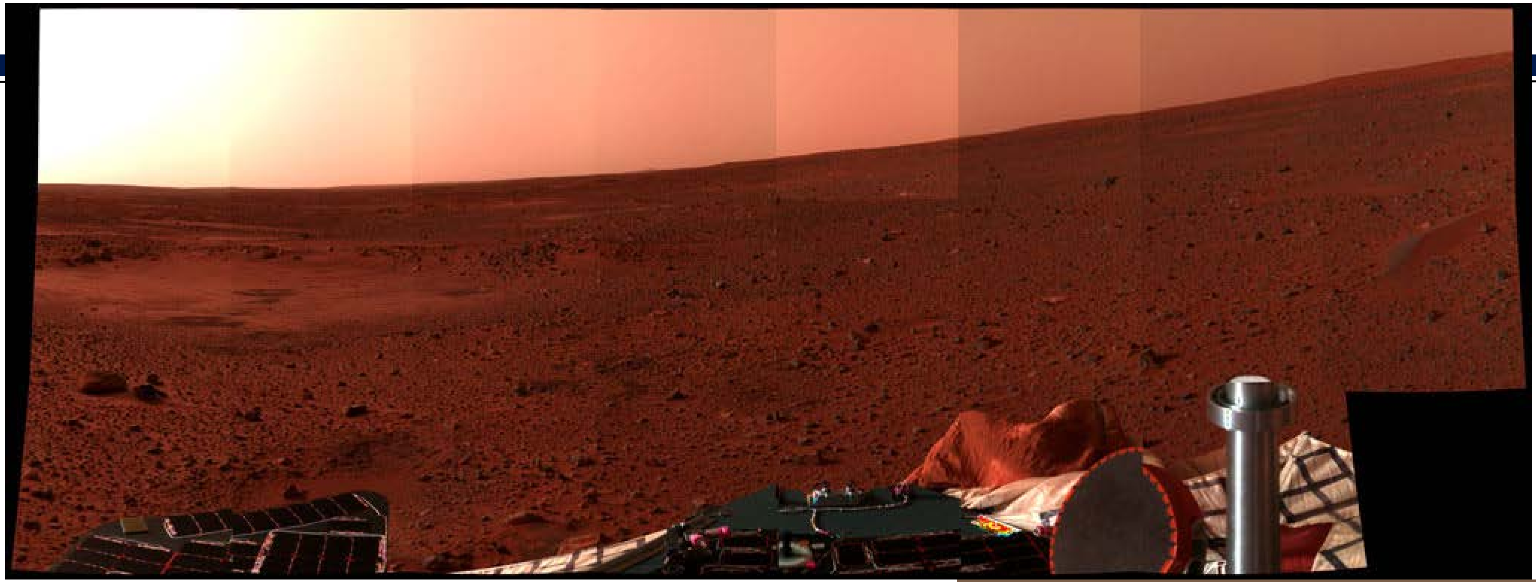
ORNL Telemanipulator Projects

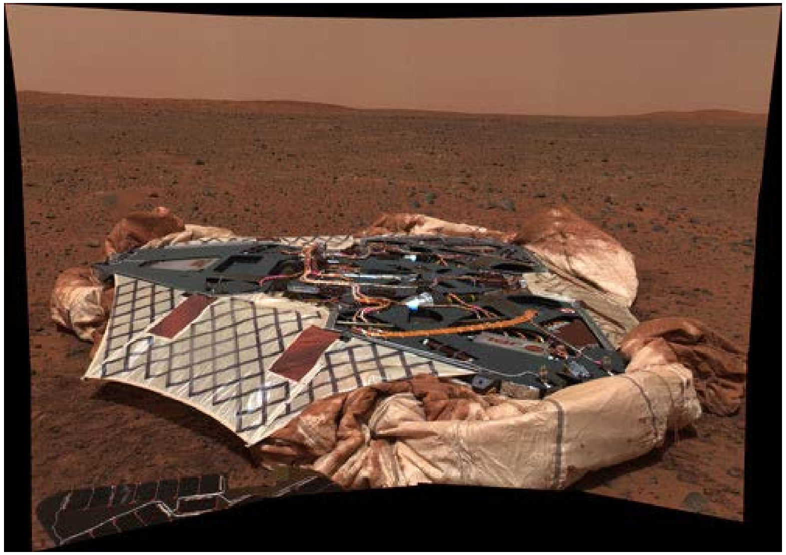
Space Robotics

- Planetary rovers:
  - One-of-a-kind
  - Significant consequences of failure
- Sojourner robot:
  - Part of PathFinder Mars Mission
  - Very successful robot
  - Explored MARS from July 5 – Sept. 27, 1997
  - Fully teleoperated

Sojourner Robot on Mars

Robots on Mars: *Opportunity* and *Spirit*





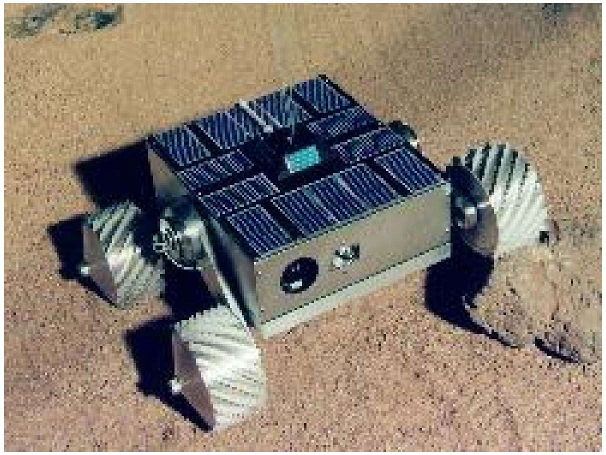
Lander

Rover

Landed on Mars in January 2004 – one is still operational!

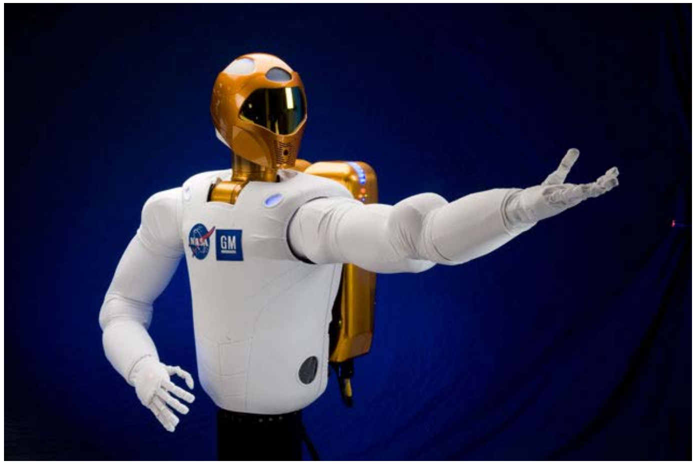
Other Space-Related Robot Designs

Challenge: Proving capabilities of autonomous systems



Nanorover, early prototype for comet mission

Rocky 7, with stereo vision and sampling manipulator



Robonaut

Autonomous Driving Robots

- 1980s: Bundeswehr University Munich; cars that drive up to 100km/h on empty streets
- 1980s: DARPA Autonomous Land Vehicle (ALV); 600m at 3km/h over complex terrain

Autonomous Driving Robots (con't.)

- 1990s: CMU's Navlab (98.2% autonomous over 5000km)

- Early 2000s: Demo I, II, III

Autonomous Driving Robots (con't.)

- 2007: DARPA Grand Challenge

- Current: Google Driverless Car

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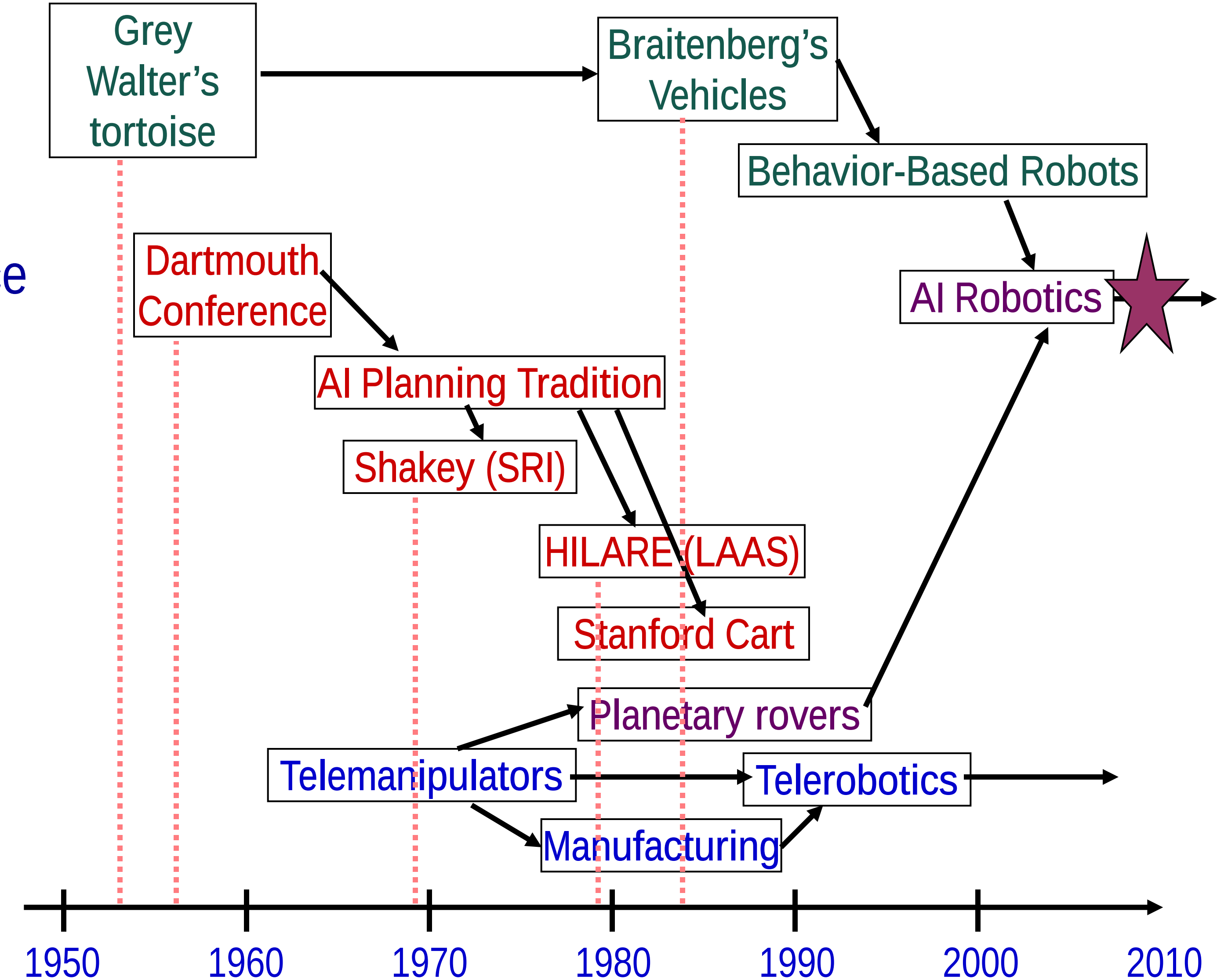

Summary

- Many threads of robotics-related research:
  - Cybernetics
  - Artificial intelligence
  - Intelligent robot precursors

- Many ongoing directions

Remember Reading Assignment

- Read Chapter 2 of Siegwart text (Locomotion)
  - We'll begin studying that material on Thursday