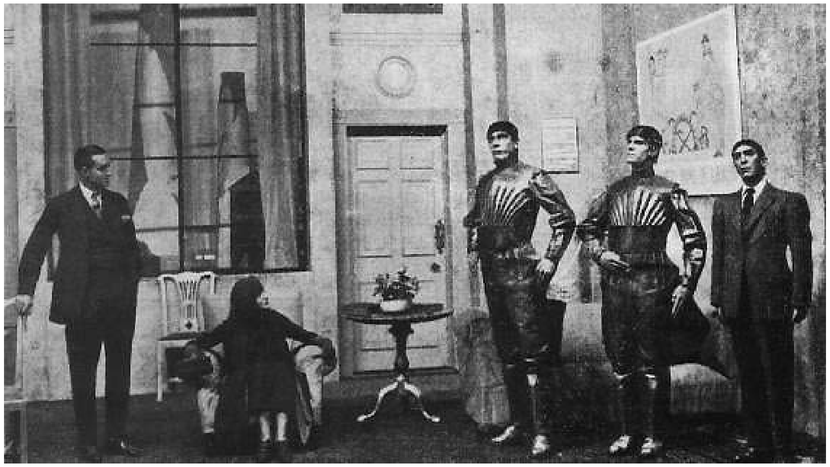
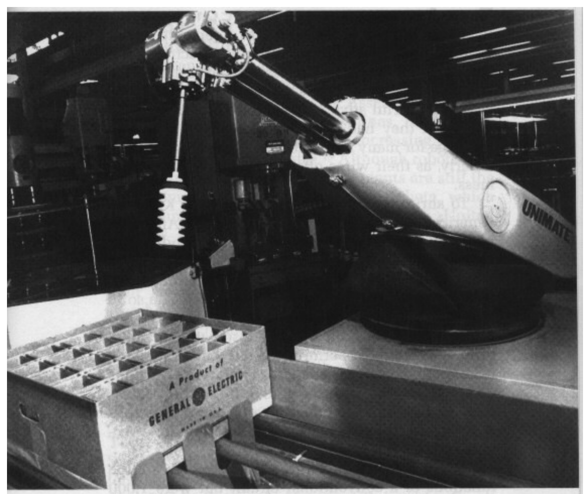
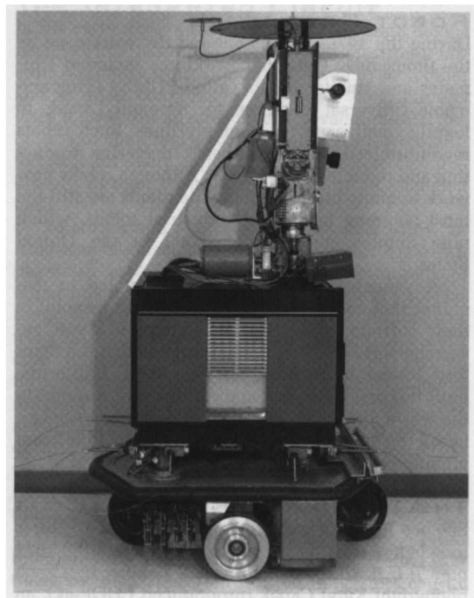


History of Intelligent Robotics



Armed for duty. A Unimate robot—really, just an arm—picks up and puts down parts in a General Electric factory.

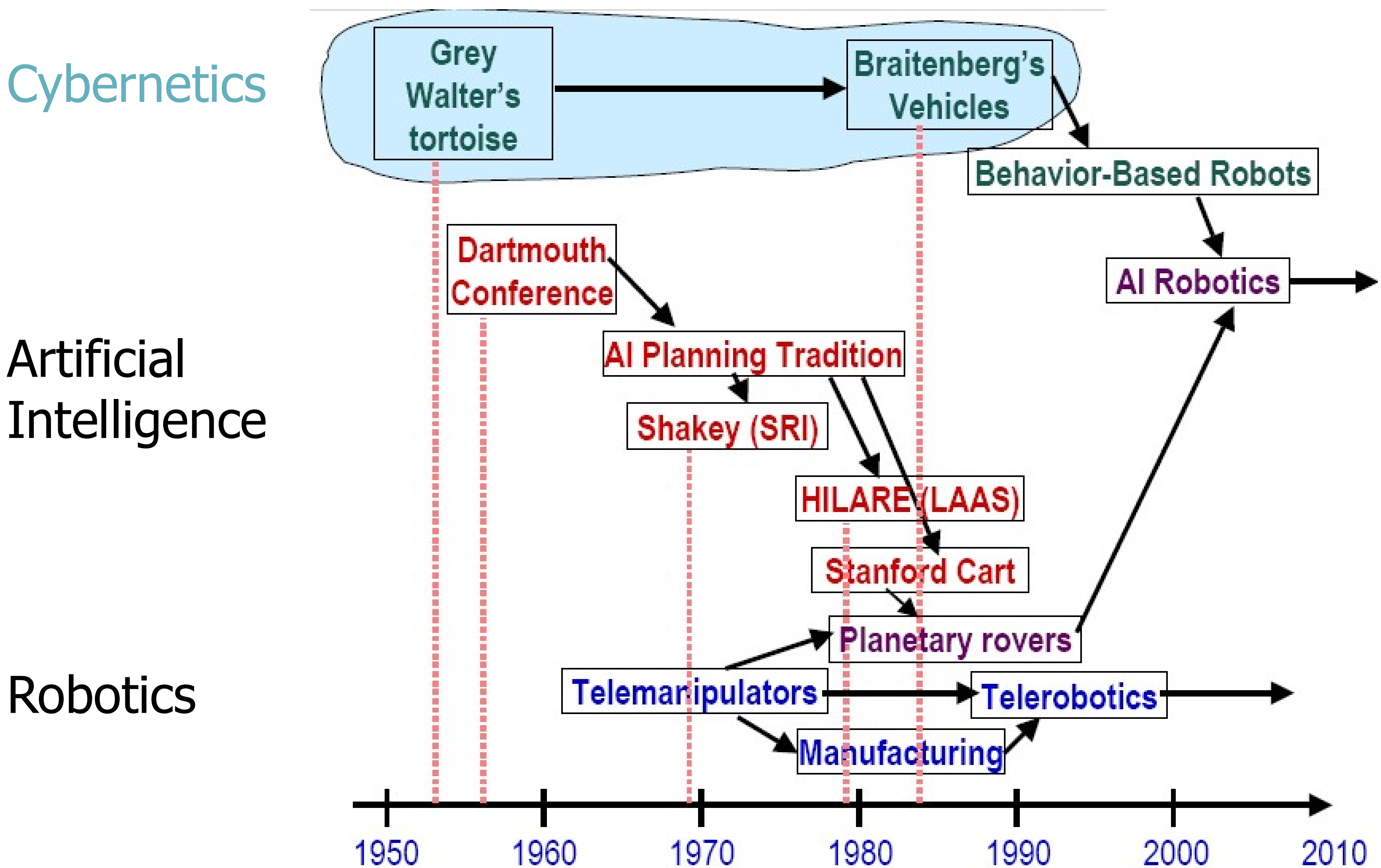


Smart and sensitive. Shakey was the first mobile robot that could think and respond to the world around it.

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

- Cybernetics is combination of:
  - Control theory
  - Information science
  - Biology
- It is the field of science concerned with processes of communication and control

- 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

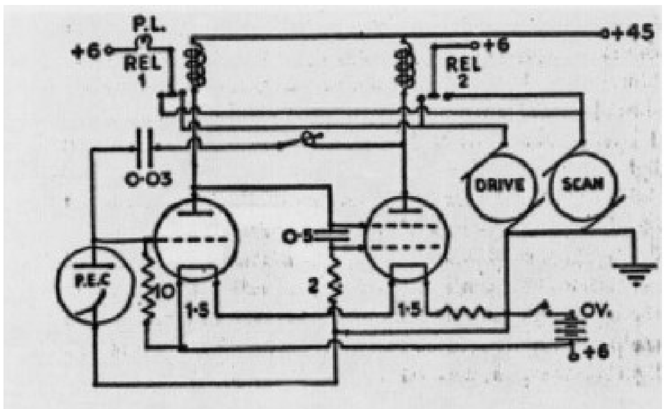
W. Grey Walter

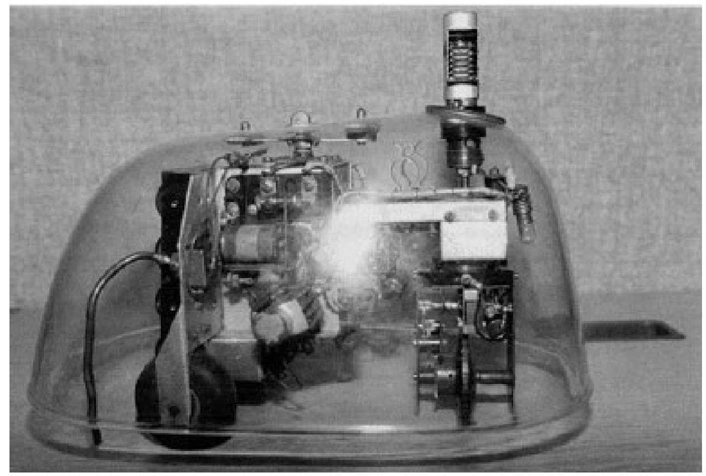
- Born in Kansas City in 1910, but raised in Cambridge, England
- Did work in 1920s with EEG (recording of electrical activity along scalp)

- Showed that certain patterns indicated person is learning
- Led to work in AI 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:
  - 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

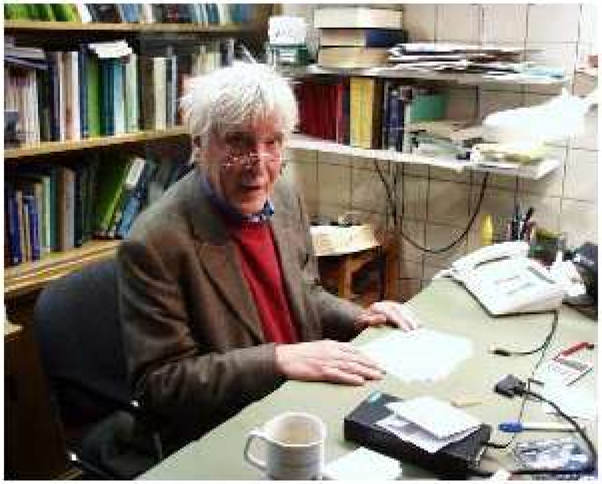
- Parsimony: simple is better
- Exploration or speculation: constant motion to avoid traps
- Attraction (positive tropism): move towards positive stimuli
- Aversion (negative tropism): move away from negative stimuli
- Discernment: distinguish between productive and unproductive behavior

- Video: http://www.youtube.com/watch?v=pPTQ4DcdAeE&feature=related
- Explanation: http://www.youtube.com/watch?v=hjxbqXd7104

Braitenberg's Vehicles (1984)

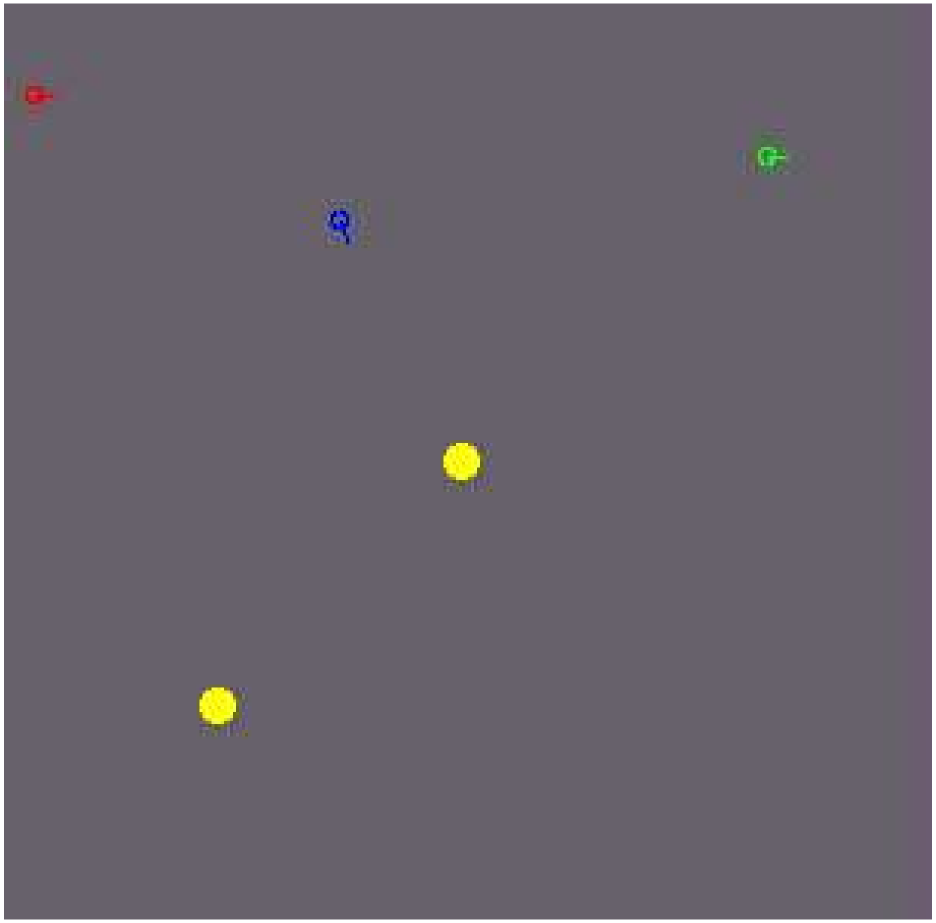
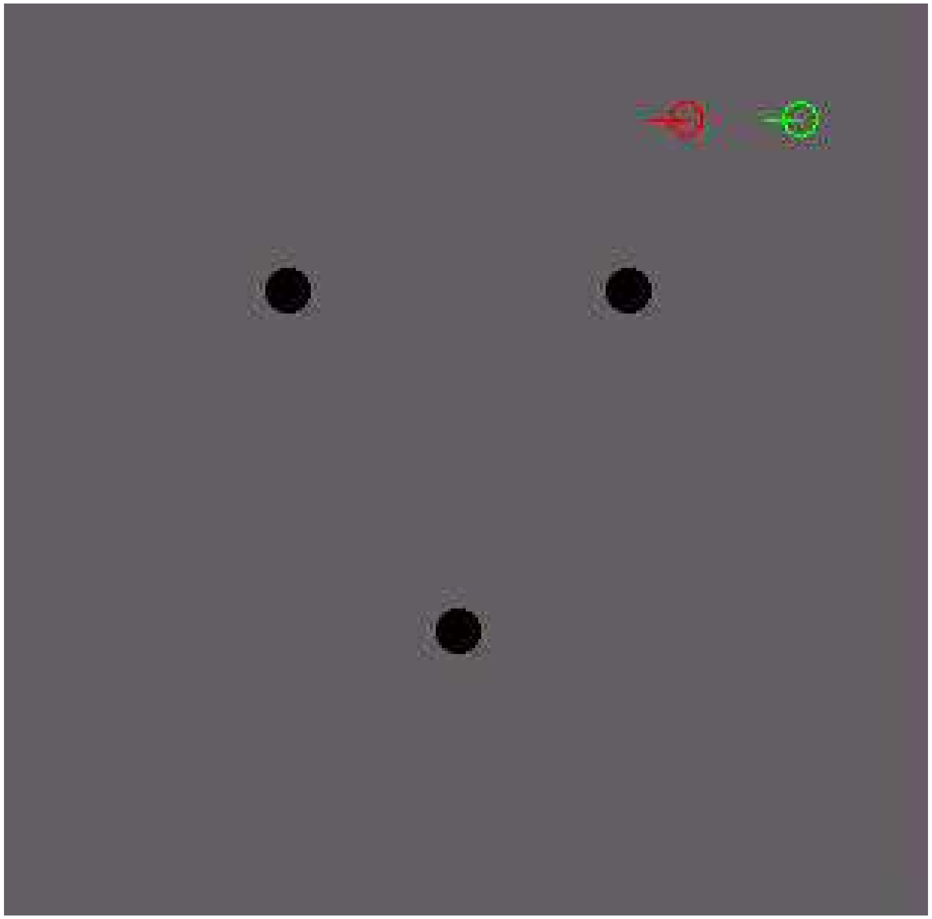
- Took perspective of psychologist
- Created wide range of vehicles
- Vehicles used inhibitory and excitatory influences
- Direct coupling of sensors to motors

- Exhibited behavioral characteristics that appeared to be:
  - Cowardice
  - Aggression
  - Love
  - Etc.



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

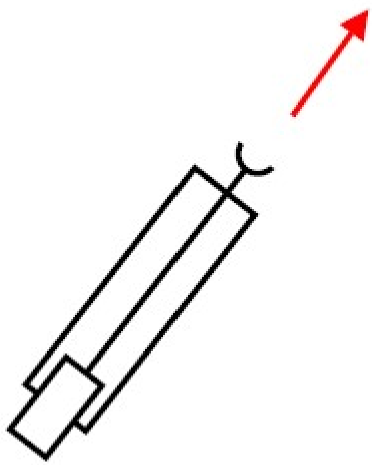
What Behaviors do You See?

Movies of some Braitenberg's vehicle

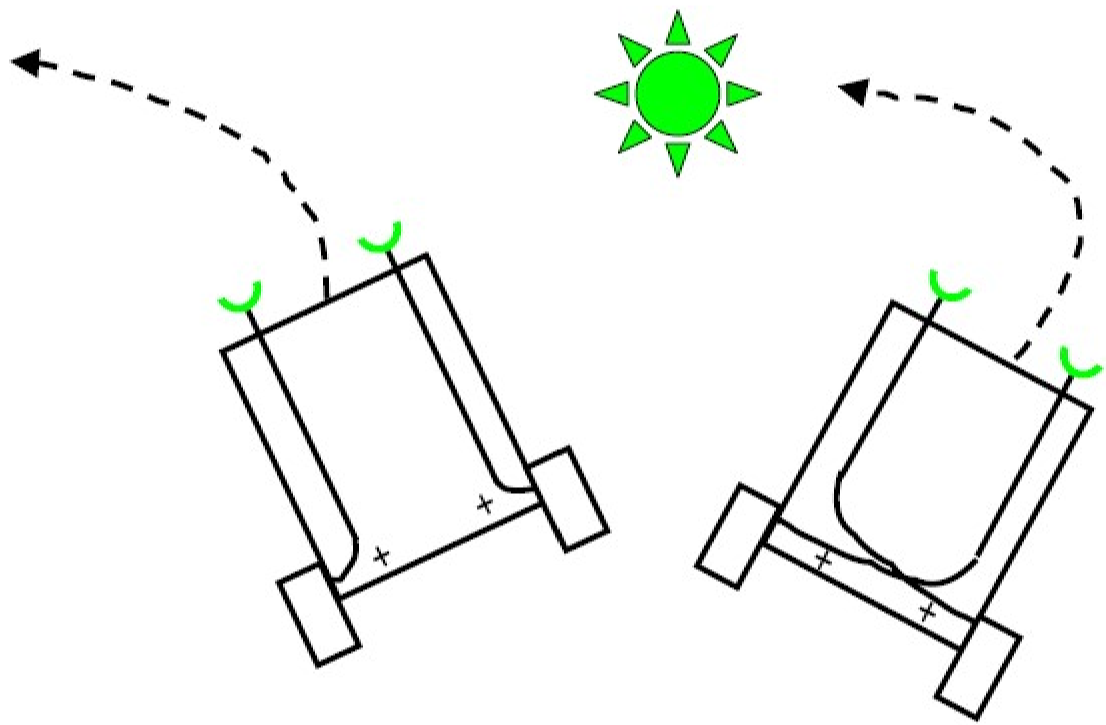
Braitenberg Vehicle 1: “Getting Around”

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



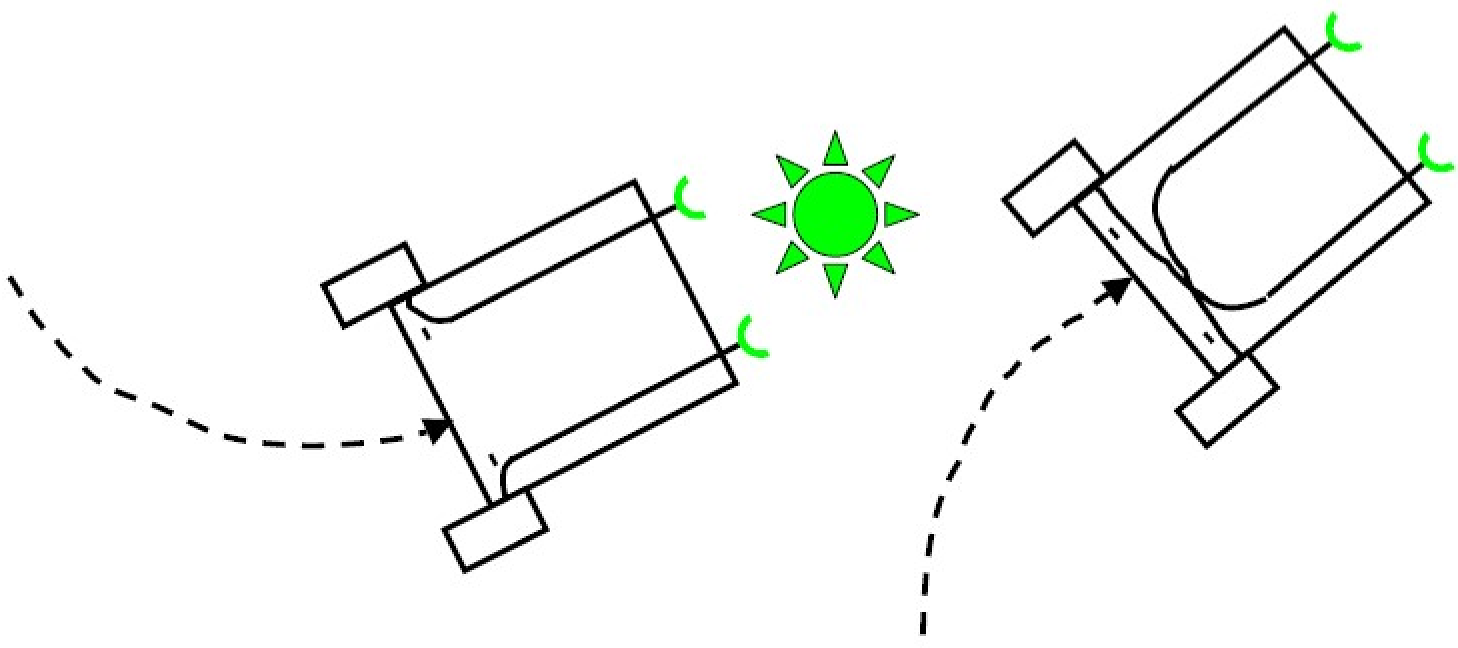
Braitenberg Vehicle 2: “Fear and Aggression”

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



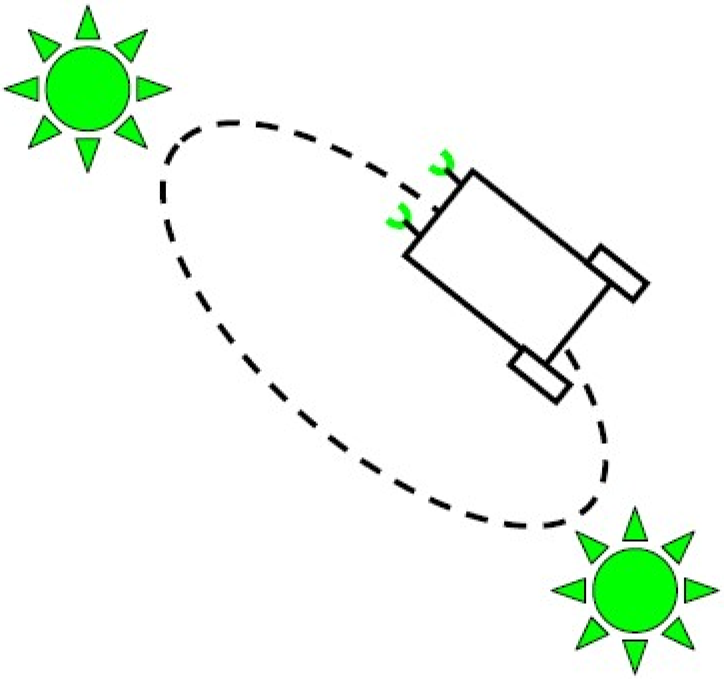
Braitenberg's Vehicle 3: "Love and Exploration"

- 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 (exploration)

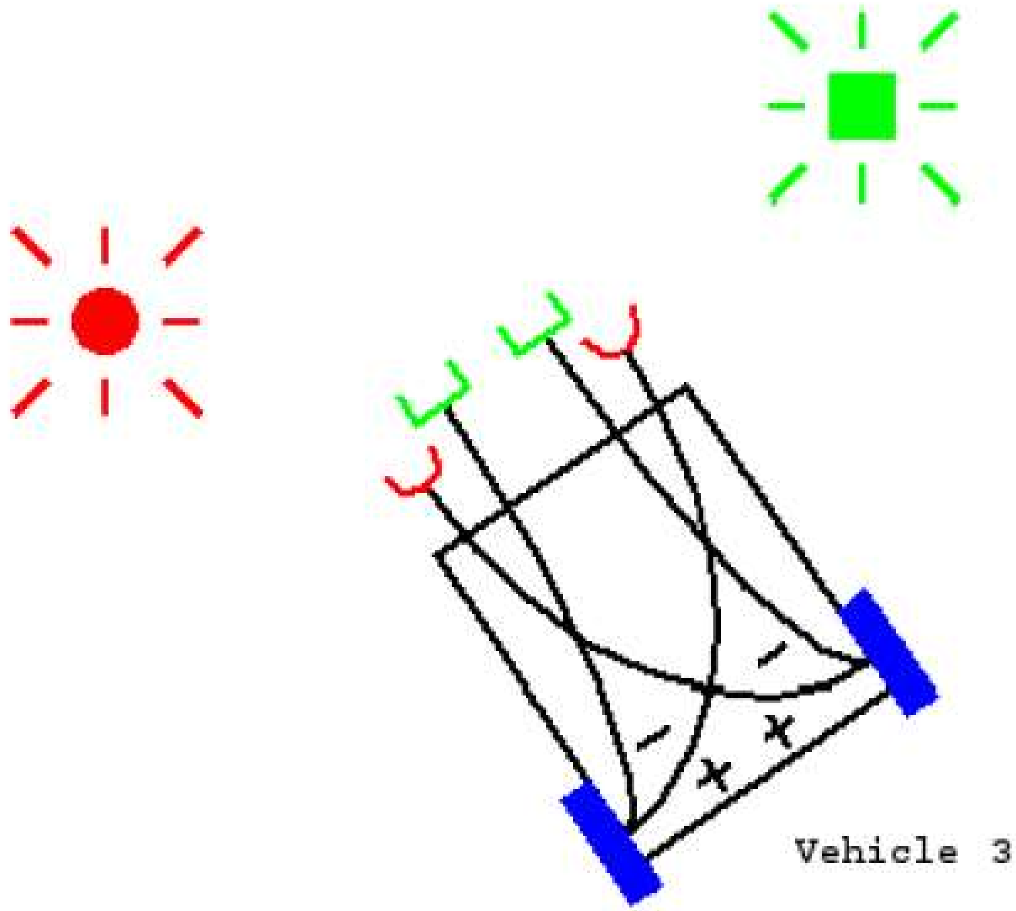


Braitenberg's Vehicle 4: "Values and Special Tastes"

- 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



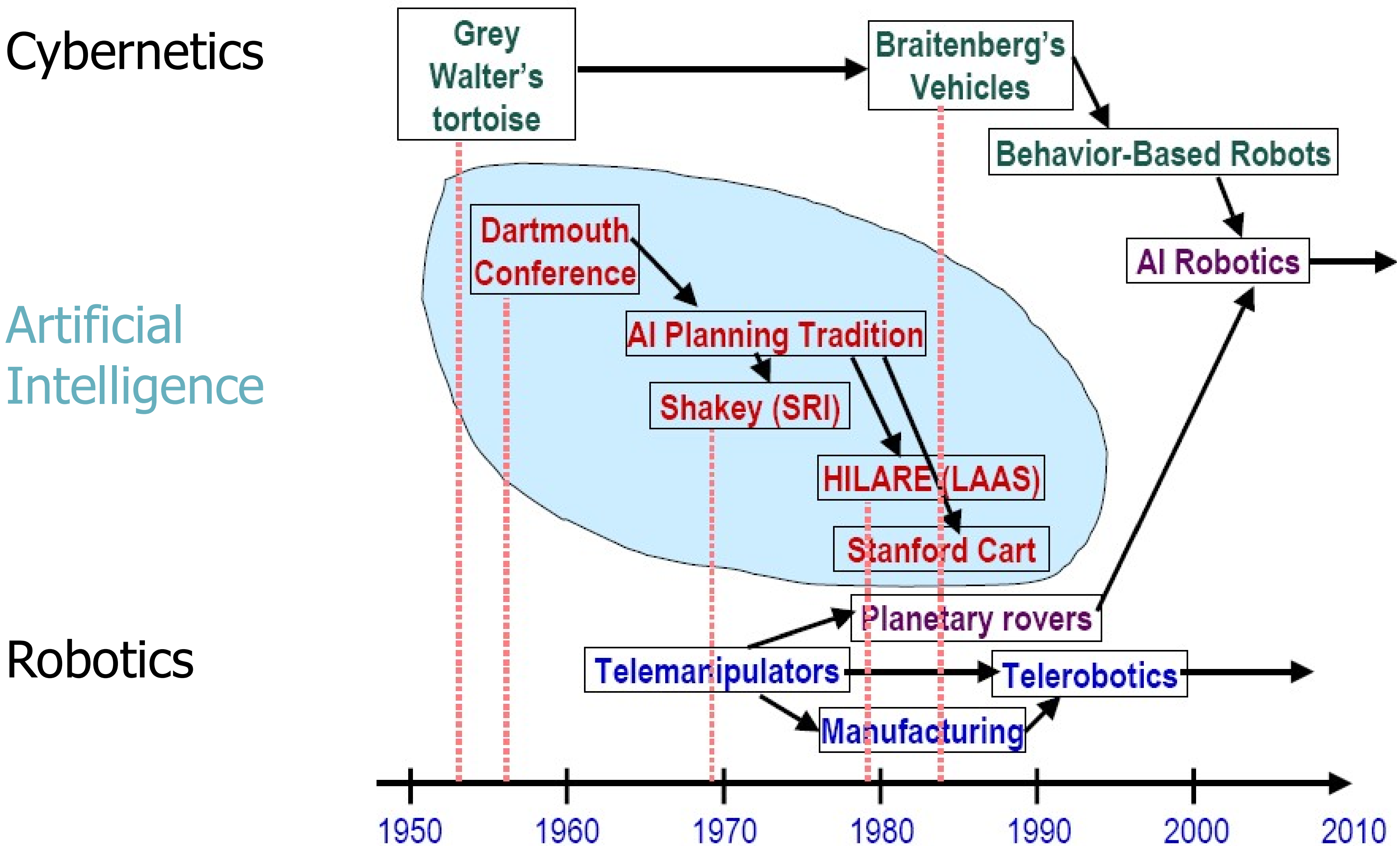
What Would You Expect of This Robot's Behavior?



Summary of Braitenberg's Vehicles

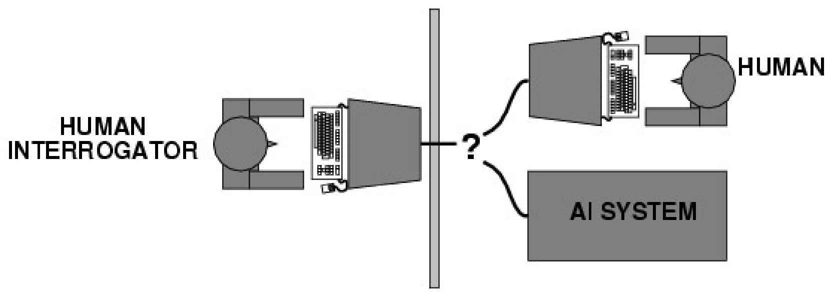
- Systems are inflexible, non-reprogrammable
- However, vehicles are compelling in overt behavior
- Achieve seemingly complex behavior from simple sensorimotor transformations
- For more information on Braitenberg's vehicles, check the following link:
  - http://www.bcp.psych.ualberta.ca/~mike/Pearl_Street/Margin/Vehicles/index.html

Historical Precursors to Today's Intelligent Robotics



Turing Test

- Turing (1950) "Computing machinery and intelligence":
- "Can machines think?" → "Can machines behave intelligently?"
- Operational test for intelligent behavior: the Imitation Game

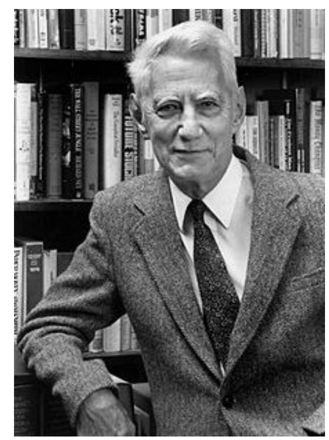


- Suggested major components of AI: knowledge, reasoning, language understanding, learning, computer vision, robotics

Artificial Intelligence (AI)

- Beginnings of AI: Dartmouth Summer Research Conference (1956)
- John McCarthy, Marvin Minsky, Nathaniel Rochester and Claude Shannon proposed the name "AI"

- The proposal discusses:
  - computers
  - natural language processing
  - neural networks
  - theory of computation
  - abstraction
  - creativity



Foundations of AI

Philosophy	Logic, methods of reasoning, mind as physical system foundations of learning, language, rationality
Mathematics	Formal representation and proof algorithms, computation, (un)decidability, (in)tractability, probability
Economics	Utility, decision theory
Neuroscience	Physical substrate for mental activity
Psychology	Phenomena of perception and motor control, experimental techniques
Computer engineering	Building fast computers
Control theory	Design systems that maximize an objective function over time
Linguistics	Knowledge representation, grammar

Early AI Roots Strongly Influenced Research

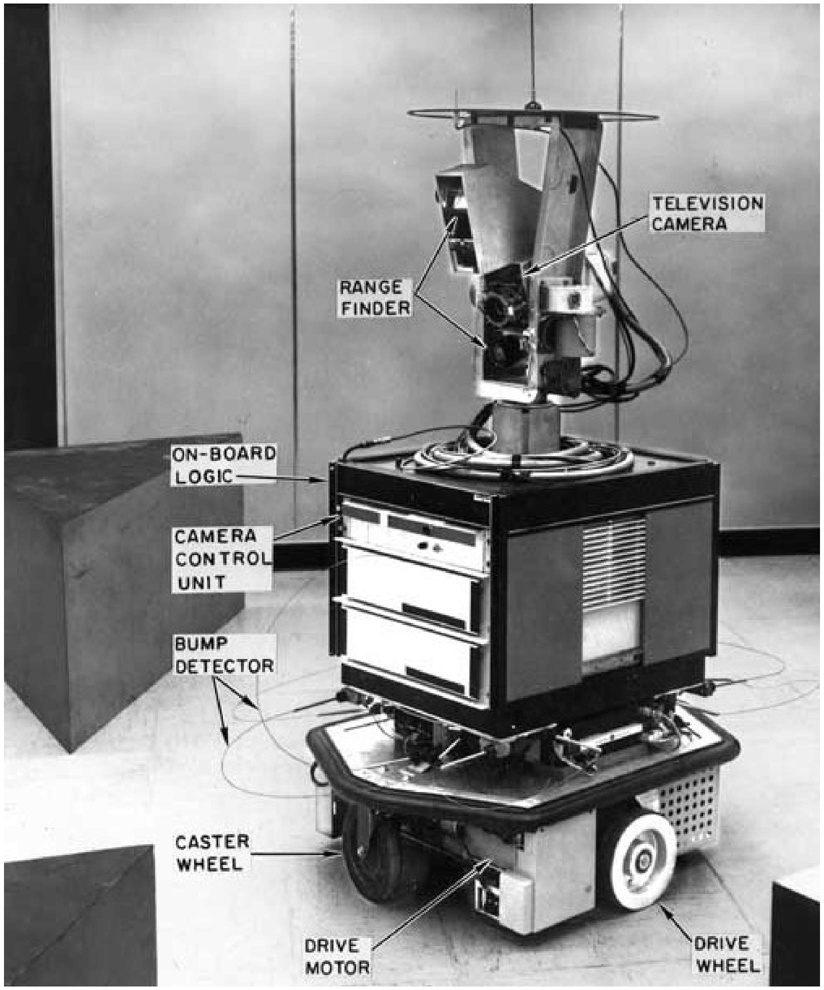
- Through mid-80's, AI research strongly dependent upon:
  - Representational knowledge
  - Deliberative reasoning methods
  - Hierarchical organization

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

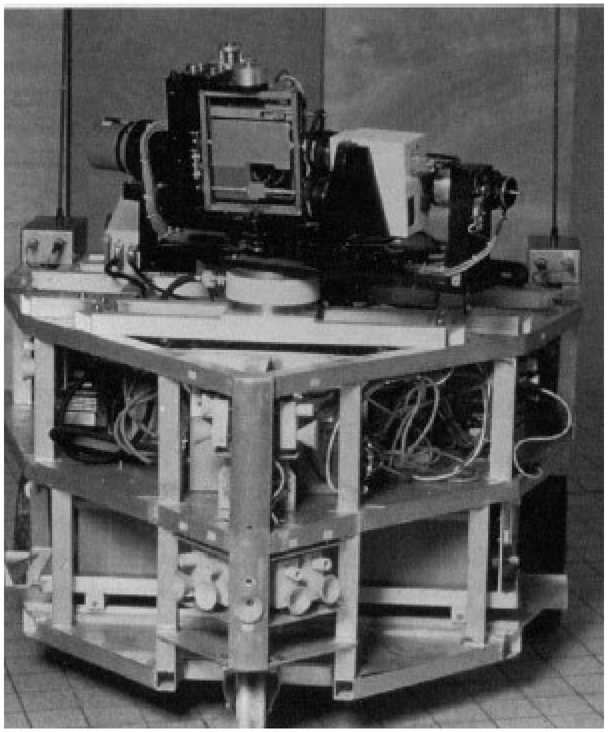
Shakey (SRI), 1960’s

- One of the first mobile robots
- Sensors
- Environment: office environment with specially colored and shaped objects
- STRIPS planner: developed for this system to determine the actions of the robot should take to achieve goals
- https://www.youtube.com/watch?v=GmU7SimFkpU



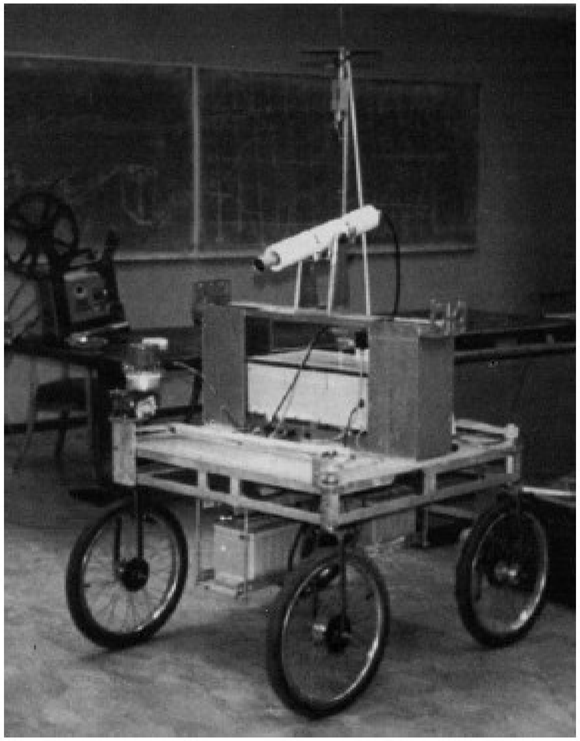
HILARE (LAAS-CNRS), 1970's

- Sensors: video camera, 14 sonars, laser range finder
- Three wheels
- World: smooth floors, office environment
- Planning:
  - Conducted in multi-level geometric representational space
- Use: for experiments for over a decade



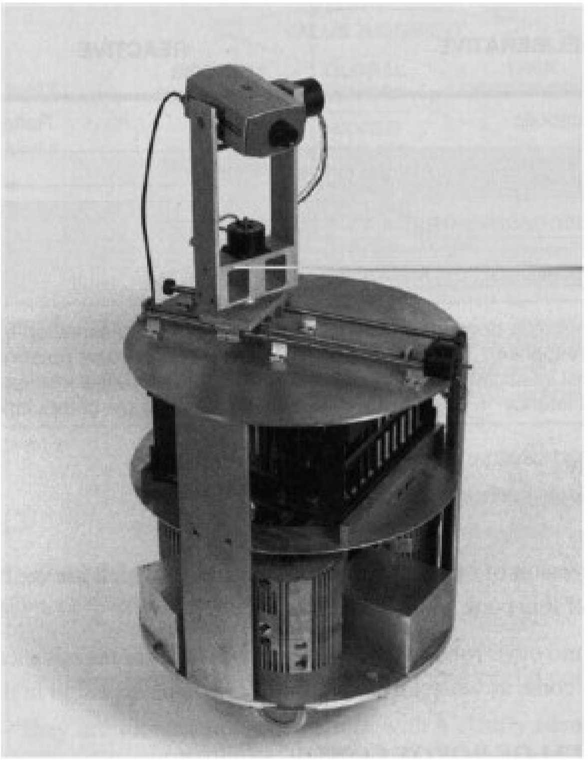
Stanford Cart, 1970's (Moravec)

- Sensors: stereo vision used for navigation
- Speed: very slow, moving at about 1 meter per 10-15 minutes
- 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



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

- Planner: generates a goal to achieve, and then constructs a plan to achieve it from the current state

- Must define representations:
  - Actions: programs that generate successor state descriptions
  - States: data structure describing current situation
  - Goals: what is to be achieved
  - Plans: solution is a sequence of actions

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

Many AI Planners in History

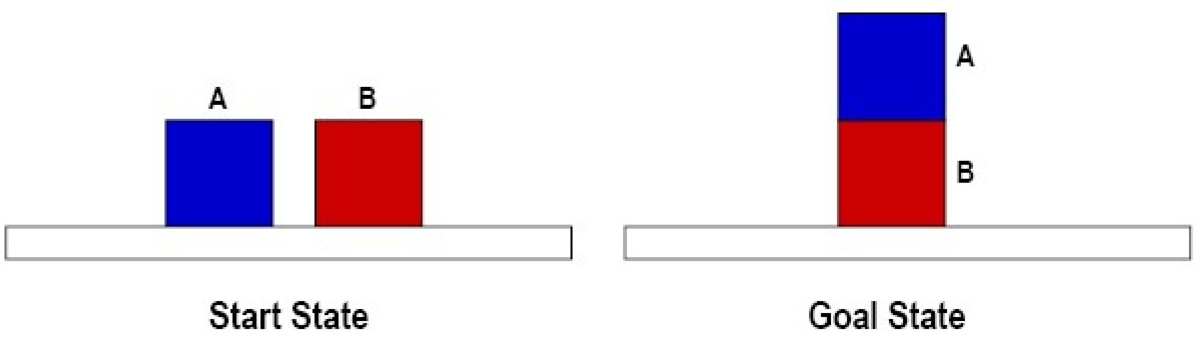
- Well-known AI Planners:
  - STRIPS (Fikes and Nilsson, 1971): theorem-proving system
  - ABSTRIPS (Sacerdoti, 1974): added hierarchy of abstractions
  - HACKER (Sussman, 1975): use library of procedures to plan
  - NOAH (Sacerdoti, 1975): problem decomposition and plan reordering

STRIPS-Based Approach to Robot Control

- Use first-order logic and theorem proving to plan strategies from start state to goal state
- Define: goal state, initial state, operators
- STRIPS operators include:
  - Action description
  - Preconditions
  - Effect:
    - Add-list
    - Delete-list

Simple Example of STRIPS-Style Planning

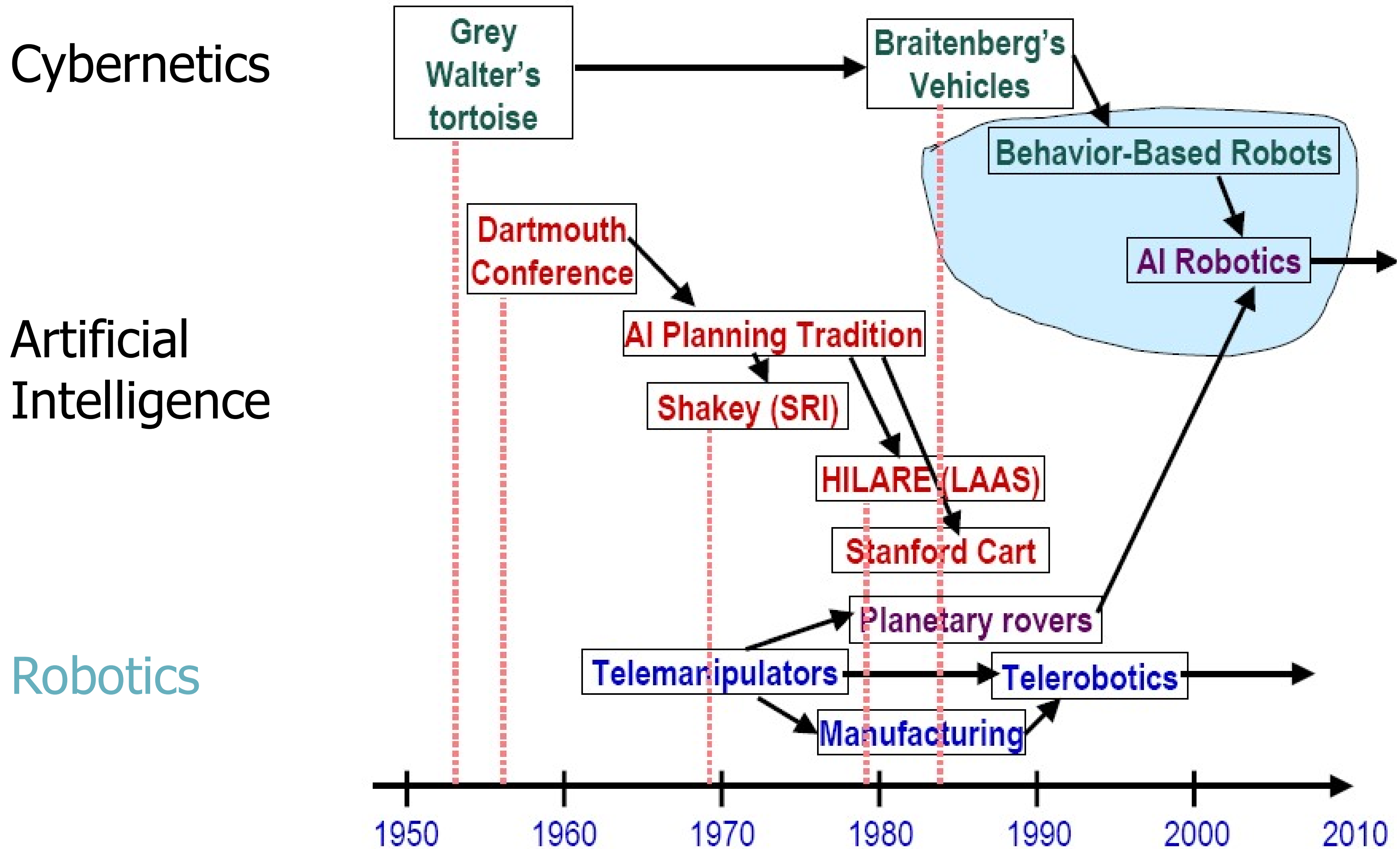
- Goal state: ON(A, B)
- Start state: ON(A, Table); ON(B, Table); EMPTYTOP(A); EMPTYTOP(B)
- Operators:
  - Move(x, y)
    - Preconditions: ON(x, Table); EMPTYTOP(y)
    - Add-list: ON(x, y)
    - Delete-list: EMPTYTOP(y); ON(x, Table)



Challenges of AI and Planning

- Closed world assumption: assumes that world model contains everything the robot needs to know: there can be no surprise
- 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

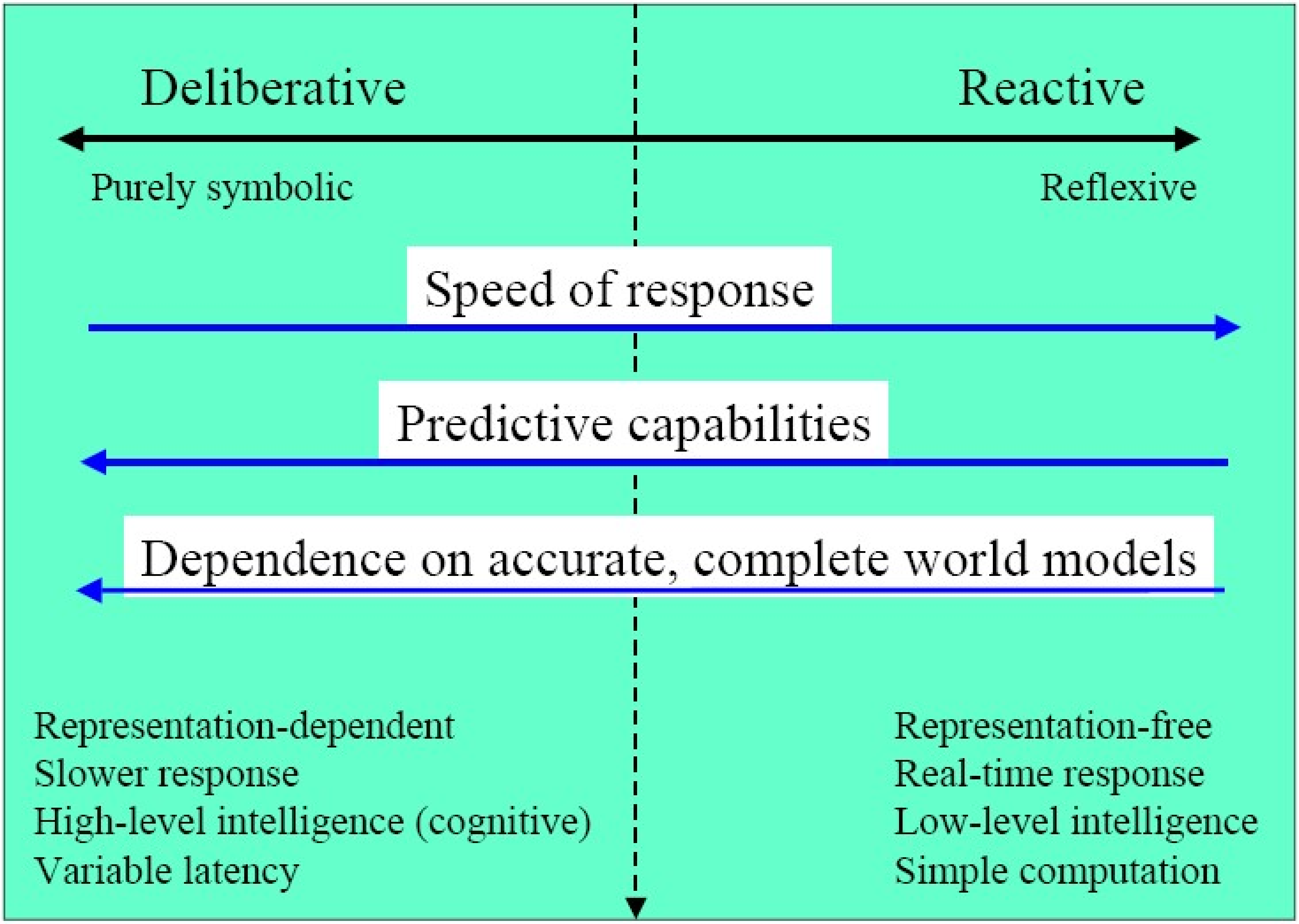


Behavior-Based Robotics' Response to Classical AI

- Reacted against classical AI
- Brooks (late 80's): "Planning is just a way of avoiding figuring out what to do next"
- Increased emphasis on:
  - Sensing and acting within environment
- Reduced emphasis on:
  - Knowledge representation
  - Planning
- https://www.youtube.com/watch?v=9u0CIQ8P_qk

Rodney Brooks, MIT, with Cog

Wide Spectrum of Robot Control



Deliberative Control

- Common characteristics:
  - Hierarchical in structure
  - Clearly identifiable division of functionality
  - Communication and control is predictable and predetermined
  - Higher levels provide subgoals for lower levels
  - Planning scope changes with descent in hierarchy
  - Heavy reliance on symbolic representations
  - Seemingly well-suited for structured and highly predictable environments (e.g., manufacturing)
- Shortcomings:
  - Lack of responsiveness in unstructured and uncertain environments

Reactive Control

- Reactive control:
  - a technique for tightly coupling perception and action, typically in the context of motor behaviors, to produce timely response in dynamic and unstructured worlds

- Behavior: stimulus/response pair

- Emergent behavior: the global behavior of robot as consequence of interaction of active individual behaviors

- Characteristics: using no world models

Key Issues of Behavior-Based Control

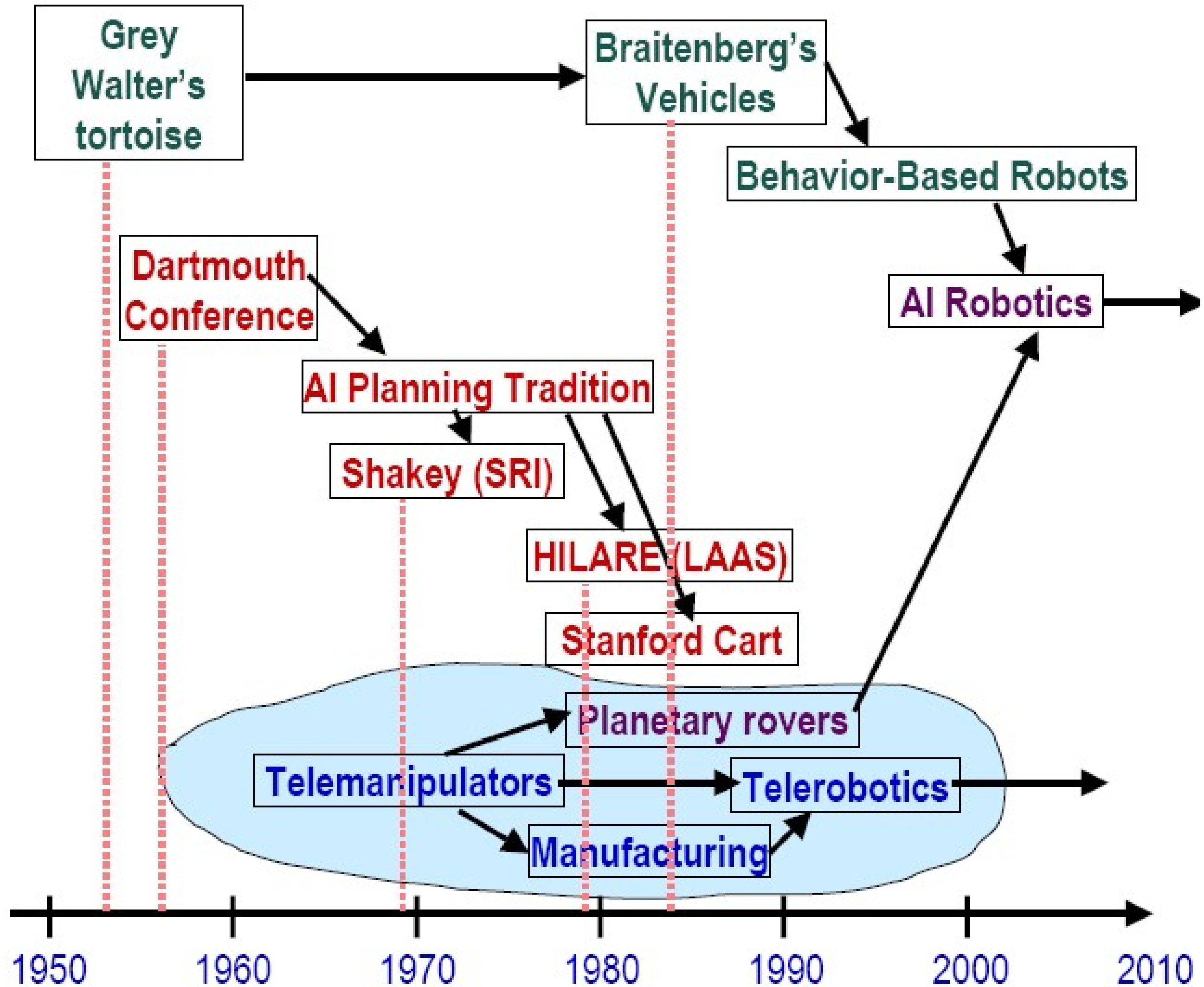
- Situatedness: robot operates in the real world
- Embodiment: robot has a physical body
- Emergence: intelligence arises from interaction of robot with environment
- Grounding in reality: avoid symbol grounding problem
- Scalability: unknown whether behavior-based control will scale to human-level intelligence

Historical Precursors to Today's Intelligent Robotics

Cybernetics

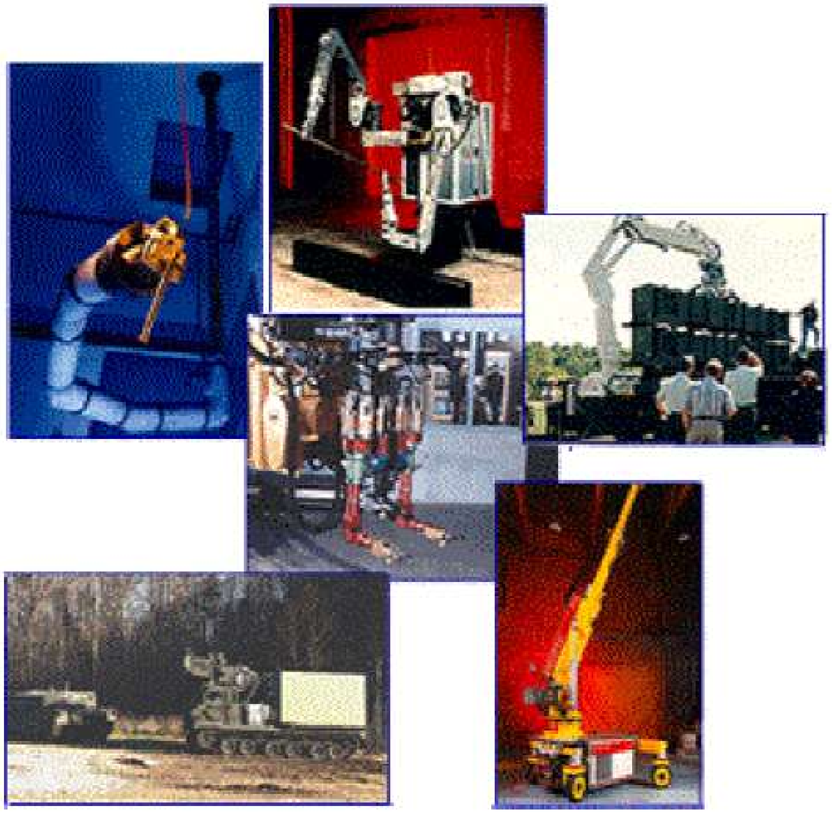
Artificial Intelligence

Robotics



Telemanipulators and Telerobotics

- Teleoperation:
  - Human operator controls robot remotely through mechanical or electronic linkage
  - https://www.youtube.com/watch?v=TJmQqC1nHTU
- Operator and robot:
  - Leader/follower relationship
  - Human leads, robot mimics human behaviors
- Issues:
  - Force feedback
  - Operator telepresence
  - Supervisory control
- Challenges:
  - Operator overload
  - Cognitive fatigue
  - Simulator sickness



ORNL Telemanipulator Projects

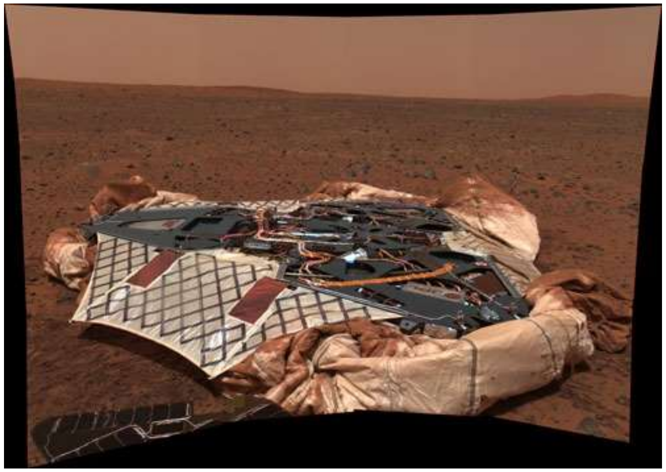
Space Robotics

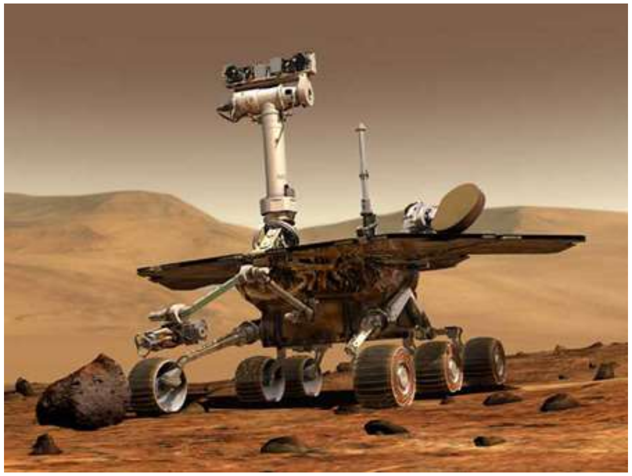
- Planetary rovers:
  - One-of-a-kind
  - Significant consequences of failure
- Sojourner robot:
  - Part of PathFinder Mars Mission
  - Very successful robot
  - Explored MARS from July 4 – Sept. 27, 1997
  - Fully teleoperated
  - The 23 lb Sojourner traveled a total of 100 meters

Sojourner Robot on Mars

http://www.robothalloffame.org/mars.html

Recent Robots on Mars: *Opportunity* and *Spirit*





Landed on Mars in January 2004!

Spirit traveled 4.8 miles, but lost her communication on Mar. 22, 2010.

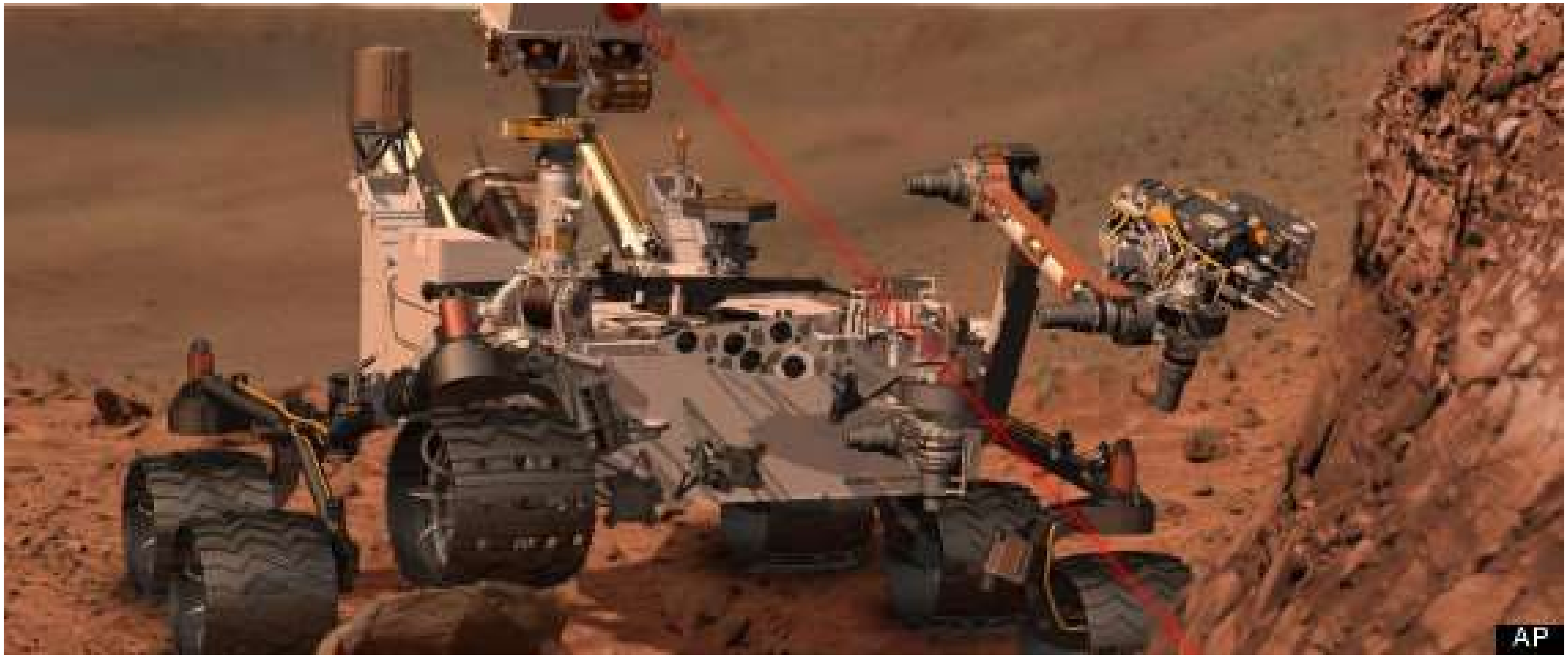
Opportunity is still in operation!! It has traveled 26.241 miles so far as of Mar. 24, 2015.

http://marsrover.nasa.gov/home/

Eventually, Space Robotics May Move More Toward Intelligent Robotics

http://www.jpl.nasa.gov/video/index.cfm?id=885

The Latest One: Curiosity



http://mars.jpl.nasa.gov/msl/multimedia/videos/index.cfm?v=147

Summary

- Many threads of robotics-related research:
  - Cybernetics
  - Artificial Intelligence
  - Intelligent robot precursors
- Primary ongoing directions:
  - Intelligent (AI) robotics
  - Telerobotics
  - Space robotics

Coming Next

- Hierarchical paradigm and STRIPS, an in-depth study