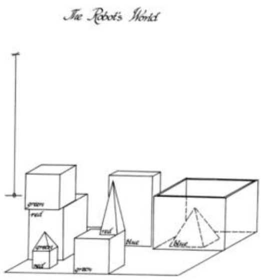
CMSC 373 Artificial Intelligence
Fall 2025



Deepak Kumar

Early Integrated AI Systems

SHRDLU & SHAKEY

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The Thinking Machine Synopsis

- Represented state-of-the-art in AI in 1961
- What makes up our thought processes?
  Studies of problem solving and game playing
- Does the nervous system work like a computer?
  No. There are some similarities but many differences.
  Dangerous to carry the analogy too far.
- Innateness versus Learning by experience
  Goose, frog, and milk experiments, click studies, perception (window)
- Intelligent behavior is rule-obeying behavior
  Figure out the rules and write them in programs
  Story generation example
- Brain has 10 billion neurons
- Predictions
  Can't imagine a computer being creative
  Computers will do things humans cannot do, or do them better
  Lead to a second industrial revolution
  There will be special purpose AI systems within 10-15 years
  We need to build general purpose machines with senses, reasoning with logic, learning, etc.

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Early AI Methodology, 1960s…

- AGI, or general AI, is too ambitious a goal.
- Use a divide and conquer approach:

  Focus on component capabilities/aspects of intelligence

  Build theories and systems that demonstrate these capabilities

  Later, integrate them into a complete system

Identifying components of intelligent behavior

- **Perception**

  Vision, hearing, touch, smell, taste, etc. Using artificial sensors (cameras, microphones, etc.)
- **Problem Solving**

  Achieving a goal. For example, solving puzzles (Missionaries & Cannibals, Towers of Hanoi, 15-puzzle), playing games (checkers, chess, go, etc.)
- **Planning**

  Purposeful problem solving. For example, how to build a tower of blocks.
- **Reasoning**

  Representing and reasoning about knowledge about the world. For example, All red colored blocks are made of wood. Block A is colored red. Is Block A made of wood?
- **Natural Language Understanding**

  Conversing in natural language(s).
- **Machine Learning**

  Learning as carried out by humans as well as using data to make predictions.
- Etc.

SHRDLU: An Integrated AI System

- Developed by Terry Winograd at MIT (1971)
- Demonstrated language interaction and problem solving in a small (toy) blocks world (**microworld**).

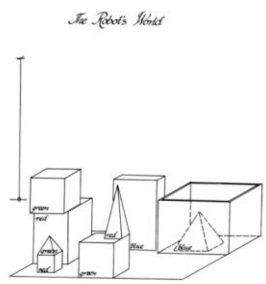
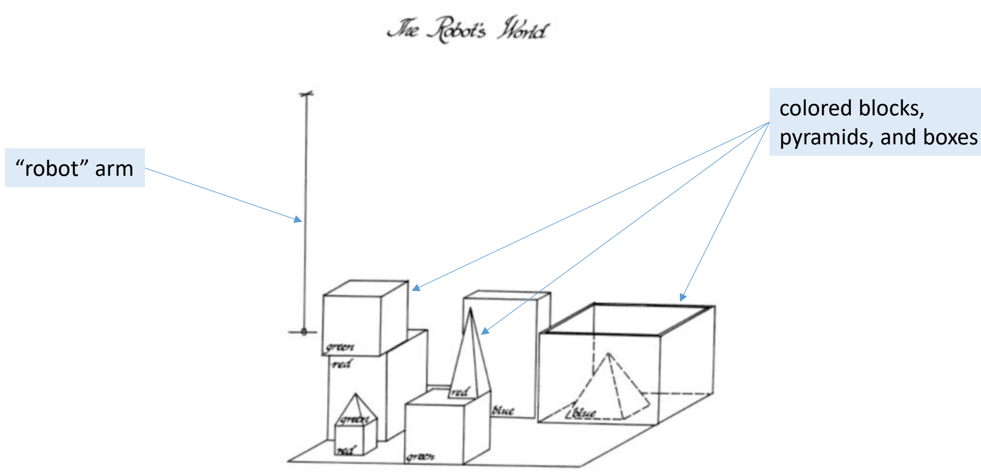
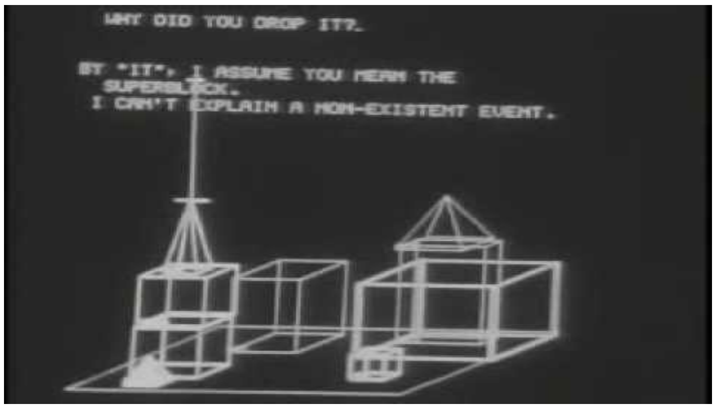


Image: From Winograd, 1971

SHRDLU (A Simulated Microworld)



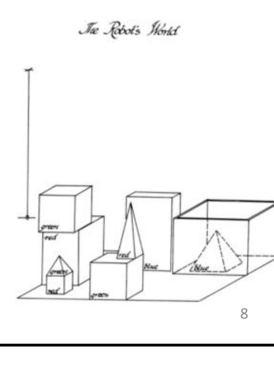
SHRDLU: Original Video



From: YouTube https://youtu.be/bo4RvYJYOzI

SHRDLU: Sample Interaction

Person: PICK UP A BIG RED BLOCK.
Computer: OK. (does it)
Person: GRASP THE PYRAMID.
Computer: I DON'T UNDERSTAND WHICH PYRAMID YOU MEAN.
Person: FIND A BLOCK WHICH IS TALLER THAN THE ONE YOU ARE HOLDING AND PUT IT INTO THE BOX.
Computer: BY "IT", I ASSUME YOU MEAN THE BLOCK WHICH IS TALLER THAN THE ONE I AM HOLDING.
Computer: OK. (does it)
Person: WHAT DOES THE BOX CONTAIN?
Computer: THE BLUE PYRAMID AND THE BLUE BLOCK.
Person: WHAT IS THE PYRAMID SUPPORTED BY?
Computer: THE BOX.
Person: HOW MANY BLOCKS ARE NOT IN THE BOX?
Computer: FOUR OF THEM.
…



From: https://hci.stanford.edu/~winograd/shrdlu/

SHRDLU: Sample Interaction

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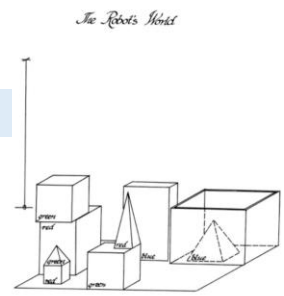
…

Ambiguous

Reflects, plans, and disambiguates.

Has a model of the world
it can answer questions about.



From: https://hci.stanford.edu/~winograd/shrdlu/

SHRDLU Design

- **Natural Language Interaction**

  Used Systemic Grammar (syntax+semantics together)

- **Planner** – three basic actions

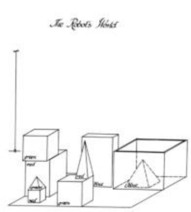
  MOVETO <location>
  GRASP <block>
  UNGRASP <block>

- **Representations:** a red block in a box

  (THGOAL (#IS ?X #BLOCK))
  (THGOAL (#COLOR $?X #RED))
  (THGOAL (#IN $?X :BOX))

- **Procedural Semantics**

  CLEARTOP X
  1. Start
  2. Does X support an object Y? If not, go to 5.
  3. Move Y from top of X. Go to 2.
  4. Assert that X is CLEARTOP



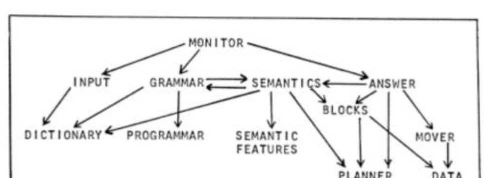


Figure 2 -- Organization of the Programs

Image: From Winograd, 1971

System was written in LISP, MicroPlanner
running on DEC PDP-10
200 word vocabulary

SHRDLU Re-implemented in Java

- Download the graphical 3-D version of SHRDLU written in JAVA from: https://hci.stanford.edu/~winograd/shrdlu/
- Interact using sentences provided in the webpage. Do some of your own.

NO LONGER AVAILABLE…

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SHRDLU: Achievements (not w/o controversies)

- A **complete AI system** with several capabilities (language, question/answering, planning, acting, etc.)
- Operated in a simulated domain (*microworld*). Also **closed**.
- Limited capabilities (but better than ELIZA!)

  Limited vocabulary (200 words)
  Only understood sentences about the blocksworld
- Argued for the development of complete systems with limited capabilities that could be expanded later.
- Considered tremendously successful and led to excessive optimism (unfounded?)

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Dichotomies of AI: Procedural vs Declarative

- **Procedural knowledge**

  aka imperative knowledge
  knowing-how to do something

- **Declarative knowledge**

  aka descriptive knowledge
  knowledge about the facts
  knowing-that

CLEARTOP X
1. Start
2. Does X support an object Y? If not, go to 5.
3. Move Y from top of X. Go to 2.
4. Assert that X is CLEARTOP
5. Done

(IS A BLOCK)
(COLOR A RED)
(IS B BOX)
(IN A B)
(CLEARTOP A)
(ON A c)

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SHAKEY the robot (1966-1972)

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SHAKEY the robot

- Developed at SRI (Stanford Research Institute)
- Integrated AI robot
- “lived” in an area with “rooms” with doorways.
- Rooms contained blocks
- Tasks were to move blocks around in different rooms
- Tasks were given using user interaction

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Image Source: https://newatlas.com/shakey-robot-sri-fiftieth-anniversary/37668/

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SHAKEY Demo (~5 min)

From: SRI’s YouTube Channel: https://youtu.be/7bsEN8mwUB8

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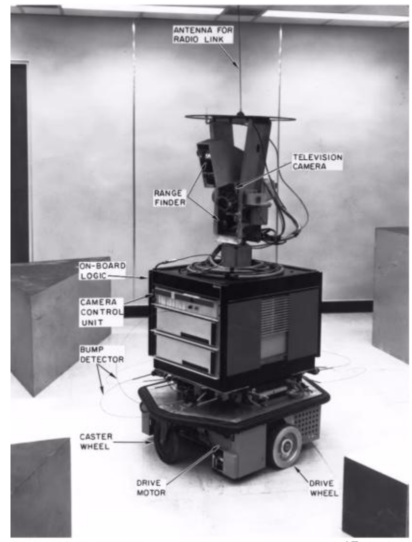
SHAKEY Capabilities

- **Sensors**
  TV camera
  Laser/sonar range finders
  Bump detectors (cat's whiskers)
  Radio Link to host computer
  Drive motors and wheels

- **Abilities**
  Constructed plans to achieve tasks
  Image analysis
  Computer vision
  Path planning



Shakey diagram photo SRI International

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SHAKEY Capabilities


Shakey solving a problem SRI International

- **Sensors**
  TV camera
  Laser/sonar range finders
  Bump detectors (cat's whiskers)
  Radio Link to host computer
  Drive motors and wheels

- **Abilities**
  Constructed plans to achieve tasks (**STRIPS Planner**)
  Image analysis (**Hough Transform** for image analysis)
  Computer vision (used **Visibility Graphs**)
  Path planning (**A* search algorithm**)
  Navigation (using **dead reckoning**)

For a longer (~24 min) video, see: https://www.youtube.com/watch?v=GmU7SimFkpU

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STRIPS Planner

- STRIPS (Stanford Research Institute Problem Solver)
- Explicit representation of **current state**
- Reasoned about **actions** to create **plans** to achieve **goals**
- Used a **planning algorithm** to formulate plans
  Essentially a **search algorithm**

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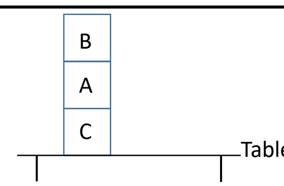
STRIPS Planner

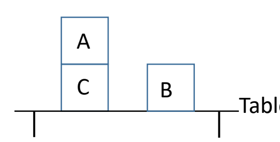


- **State** – represented as a set of facts

  {On(B, A), Clear(Table), On(A, C), On(C, Table), Clear(B)}

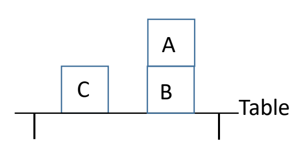
- **Goal**

  G1: On(B, Table)
  G2: On(B, Table) ∧ On(A, B)



- **Actions** – represented as **operators** (STRIPS Operators)

  action(<parameters>): description
  pre-conditions list
  delete list
  add list



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STRIPS: Action Schema

action(<parameters>): description
pre-conditions list
delete list
add list

action(<parameters>): description
pre-conditions: <facts that need to be true>
delete: <facts that will no longer be true after action is performed>
add: <Facts that will become true after action is performed>

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STRIPS: Action Schema

action(<parameters>): description
pre-conditions: <facts that need to be true>
delete: <facts that will no longer be true after action is performed>
add: <Facts that will become true after action is performed>

- Example:

move(x, y, z): move x from y to z
preconditions: [On(x, y), Clear(x), Clear(z)]
delete: [Clear(z), On(x, y)]
add: [On(x, z), Clear(y), Clear(Table)]

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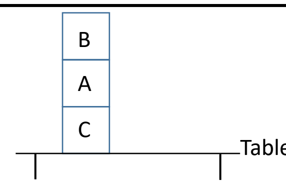
STRIPS Assumption

action(<parameters>): description
  pre-conditions list
  delete list
  add list

Besides what is specified about the way facts are added or removed, nothing else changes.

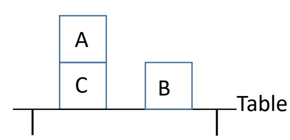
This was the STRIPS solution to the **Frame Problem** (the problem of having to explicitly specify everything that does not change when any action is carried out).

STRIPS: Planning as Search



- **Initial State**

  {On(B, A), Clear(Table), On(A, C), On(C, Table), Clear(B)}



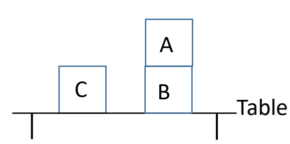
- **Goal**

  G1: On(B, Table)
  G2: On(B, Table) ∧ On(A, B)

- **Actions**

  move(x, y, z): move x from y to z

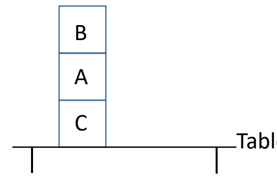
  preconditions: On(x, y) ∧ Clear(x) ∧ Clear(z)
  delete: Clear(z), On(x, y)
  add: On(x, z), Clear(y)



STRIPS: Example 1

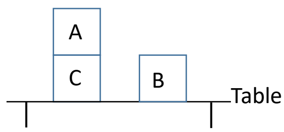
- **Initial State**

  {On(B, A), Clear(Table), On(A, C), On(C, Table), Clear(B)}



- **Goal**

  On(B, Table)



- **Plan**

  [move(B, A, Table)]

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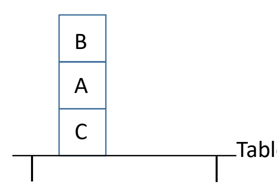
STRIPS: Example 2

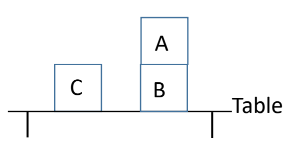
- **Initial State**

  {On(B, A), Clear(Table), On(A, C), On(C, Table), Clear(B)}



- **Goal**

  On(B, Table) ∧ On(A, B)



- **Plan**

  [move(B, A, Table), move(A, C, B)]

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Try this: Class Exercise

Actions: Pickup(<Block>), Putdown(<Block>, <location>)

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SHRDLU: Looking back

- Showed natural language interaction with understanding (as opposed to ELIZA) in an integrated AI system.
- Though, the dialogs were very constrained in a microworld with a limited vocabulary.
- Gave hope that the techniques used in SHRDLU might provide a route to much more general natural language understanding systems.
- Argued for the use of **procedural knowledge** in its planning/problem solving component. Many people opposed this idea.
- Highly influential and remains one of the landmark AI systems.

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SHAKEY: Looking back

- Showed how one could combine perception (vision), planning, navigation and path planning in an embodied robot.
- First robot to reason about its actions
- Led to fundamental advances in visual analysis (Hough Transform, Visibility Graphs), route finding (A* algorithm), and planning of complex actions (STRIPS)
- Building robots is expensive, time-consuming, difficult, daunting, and challenging. Designers had to greatly simplify the challenges faced by the robot. E.g. Power to onboard TV cameras, specially constructed environment, very slow computers.
- "Shakey also helped open the possibilities of computer science to the public's imagination and put SRI's Artificial Intelligence Center on the map." -: Ray Perrault, PhD, director of SRI International's Artificial Intelligence Center (2015)
- Funding for the project was from US Department of Defense.

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SHAKEY Funding

- ARPA (Advanced Research Projects Agency)
  US Department of Defense
  Also, National Science Foundation (NSF)
  and Office of Naval research (ONR)
- **Deceptive Project Title:** *Automaton for Reconnaissance*
  Funding was to find way for robots and AI to do military reconnaissance (a robot scout)

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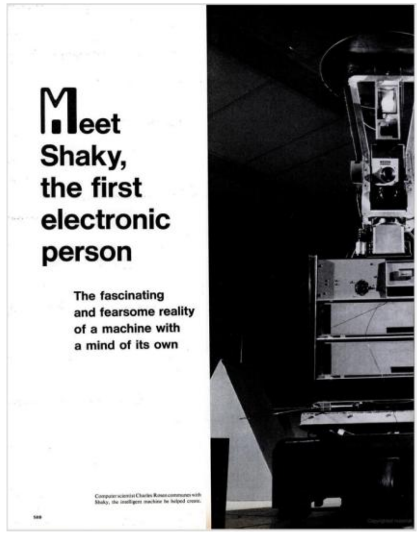
SHAKEY in the news (Hype!)



LIFE Magazine, November 1970

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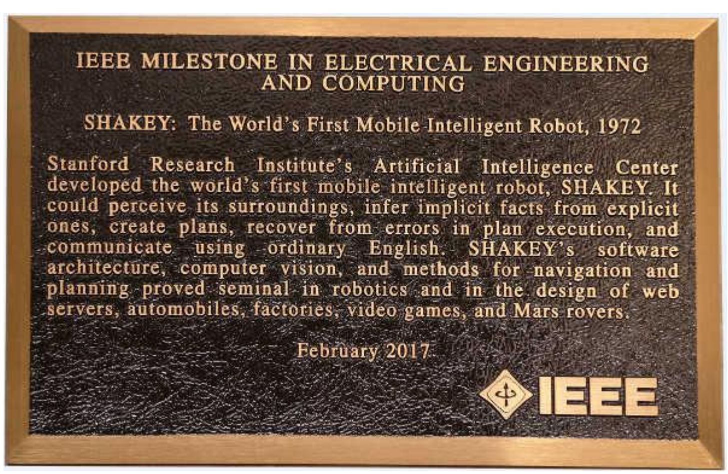
SHAKEY Commemorated (2017)



See: IEEE Spectrum Magazine, February 2017
Link: https://spectrum.ieee.org/sri-shakey-robot-honored-as-ieee-milestone

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Implications and Current Status

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Amazon.com Warehouse Robots

https://www.youtube.com/watch?v=4sEVX4mPuto

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Amazon.com Warehouse Robots

See new video (From May 2025):https://youtu.be/2X4CU3jmw-g?si=2f_4cDBwcu7BpV03

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Vocabulary Review

Perception
Problem Solving
Planning
Reasoning
Natural Language Understanding
Machine Learning
SHRDLU
Microworld
Procedural Knowledge
Declarative Knowledge
SHAKEY
STRIPS
State
Goal
Actions/Operators/Schema
Closed World
Frame Problem

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References

- The Thinking Machine (video). MIT/Carousel Films, 1961. Available at: https://youtu.be/5YBIrc-6G-0
- M. Wooldridge: A Brief History of Artificial Intelligence. Flatiron Books, 2020.
- T. Winograd: Procedures as a Representation for Data in a Computer Program for Understanding Natural Language. PhD Thesis, MIT AI Technical Report 235. 1971.
- T. S. Perry. SRI's Pioneering Mobile Robot Shakey Honored as IEEE Milestone, IEEE Spectrum, February 1970. Link: https://spectrum.ieee.org/sri-shakey-robot-honored-as-ieee-milestone
- A* Search. Brilliant Worldwide Inc. Link: https://brilliant.org/wiki/a-star-search/

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