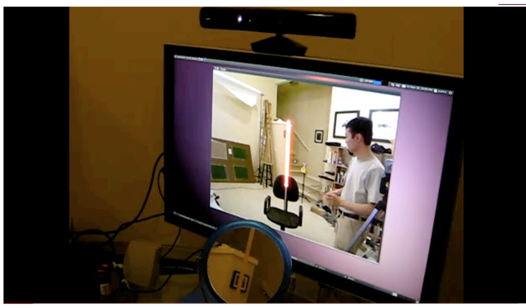


http://www.youtube.com/watch?v=3EeJCln5KYg

+

Robotics

CS151
David Kauchak

Some material adapted from slides from Zach Dodds

+ Admin

- Status reports
- Assignment 5 graded
- Exam #2 on Wednesday in class
- Paper draft (e-mailed) next Tuesday
- CS lunch tomorrow

+ What is a robot?

"I can't define a robot, but I know one when I see one."
--Joseph Engelberger (1966)

Justice Potter Stewart wrote in Jacobellis v. Ohio (1964), "I can't define pornography, but I know it when I see it."

Robot Defined

- Word robot was coined by a Czech novelist Karel Capek in a 1920 play titled Rossum's Universal Robots (RUR)
- Robota in Czech is a word for worker or servant


Karel Capek

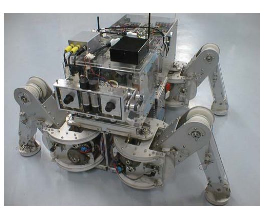
- Definition of robot:
  - –Any machine made by by one our members: Robot Institute of America ☺
  - –A robot is a reprogrammable, multifunctional manipulator designed to move material, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks: Robot Institute of America, 1979

What is a Robot

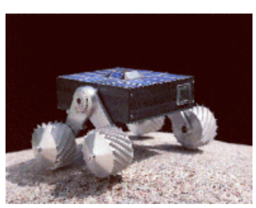
Manipulator

What is a Robot

Legged Robot

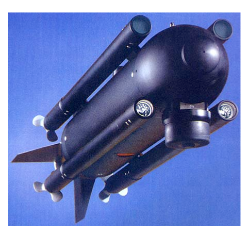


Wheeled Robot

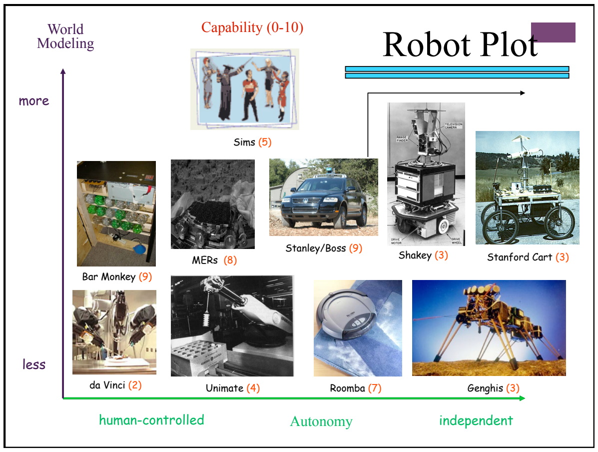


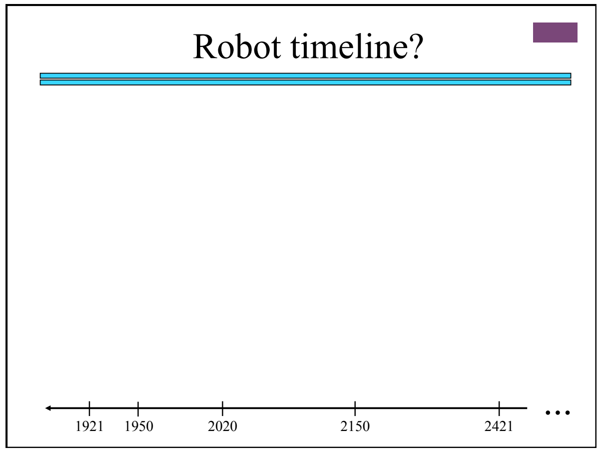
What is a Robot

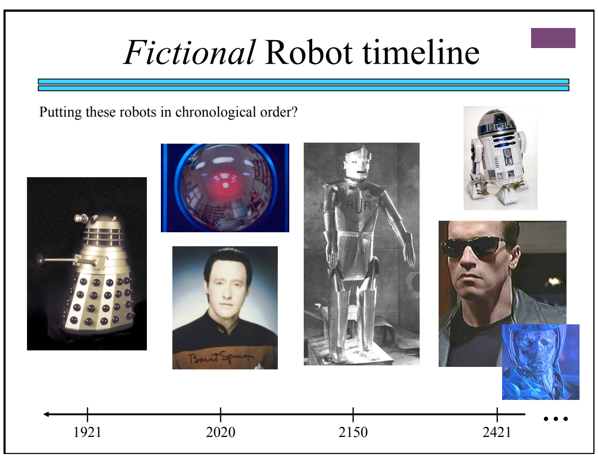
Autonomous Underwater Vehicle

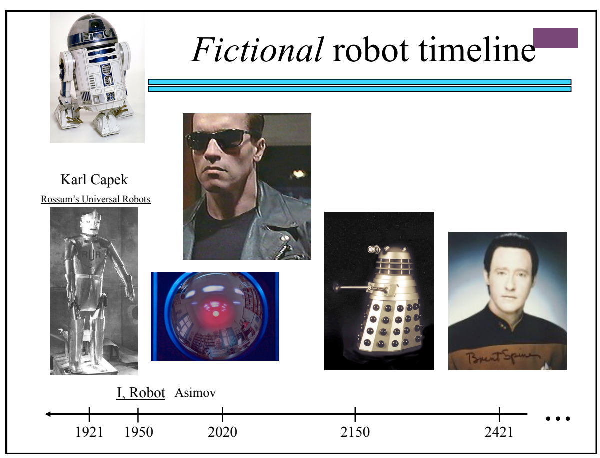


Unmanned Aerial Vehicle


Robot Plot
World Modeling
Capability (0-10)
more
less
Sims (5)
Bar Monkey (9)
MERs (8)
Stanley/Boss (9)
Shakey (3)
Stanford Cart (3)
da Vinci (2)
Unimate (4)
Roomba (7)
Genghis (3)
human-controlled
Autonomy
independent


Robot timeline?
1921
1950
2020
2150
2421
…


Fictional Robot timeline
Putting these robots in chronological order?
1921
2020
2150
2421
…

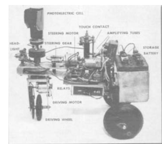

Fictional robot timeline
Karl Capek
Rossum's Universal Robots
I, Robot Asimov
1921
1950
2020
2150
2421
…

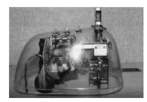
Real robot timeline

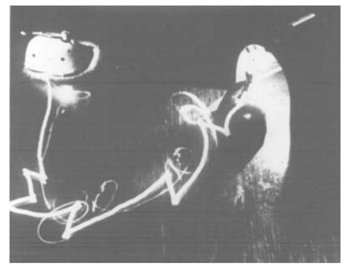
← 1951 — 1968 — 1976 — 1985 — …

Real robot timeline

Tortoise "Elsie"





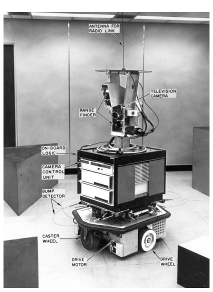


by Neurophysiologist Grey Walter

← 1951 — …

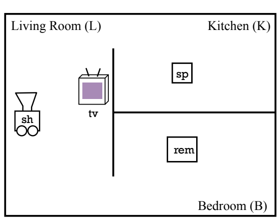
http://www.frc.ri.cmu.edu/~hpm/talks/revo.slides/1950.html

Shakey



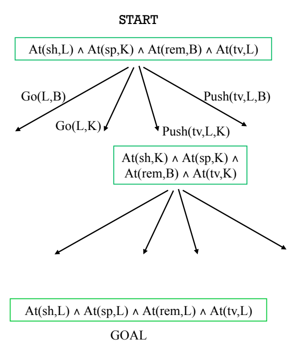
Nils Nilsson @ Stanford Research Inst.

first "general-purpose" mobile platform



… — 1968 — …

Robotics's *Shakey* start



ACTIONS

- Go(from,to)

Preconditions: At(sh,from)
Postconditions: At(sh,to)

- Push(obj,fr,to)

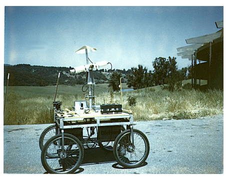
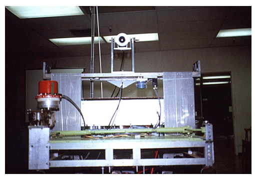
Preconditions: At(sh,fr) ∧ At(obj,fr)
Postconditions: At(sh,to) ∧ At(obj,to)

Stanford Cart: *SPA*

Hans Moravec @ SAIL

"functional" task decomposition →
"horizontal" subtasks

SENSING | perception | world modeling | Planning | task execution | motor control | ACTING

… 1976 …

Cartland (outdoors)

Cartland (indoors)

"Robot Insects"

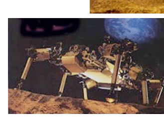
Rodney Brooks @ MIT

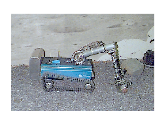
"behavioral" task decomposition →
"vertical" subtasks

SENSING

- planning and reasoning
- identify objects
- build maps
- explore
- wander
- avoid objects

ACTING



… 1985 …

+ Robotics

What are the challenges?
How do these relate to AI?

+ AI

- Search
  - planning
- Game playing
- CSPs
- Bayesian
- HMMs
- Machine learning
  - neural nets
- Knowledge representation
- Natural Language processing
- Computer vision

Autonomy/behavior

how much of the world do we need to represent internally ?

Robot Architecture

how should we internalize the world ?

what outputs can we effect ?

what inputs do we have ?

what algorithms connect the two ?

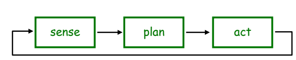
how do we use this "internal world" effectively ?

Robot Architecture

how much / how do we represent the world internally ?

As much as possible!

SPA paradigm



Not at all

Reactive paradigm

Task-specific

Behavior-based architecture

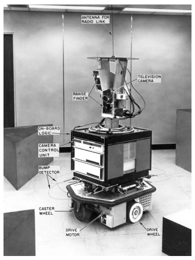
As much as possible.

Hybrid approaches

history…

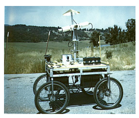
Sense - Plan - Act

Shakey

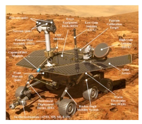


SENSING | perception | world modeling | planning | task execution | motor control | ACTING

sense → plan → act



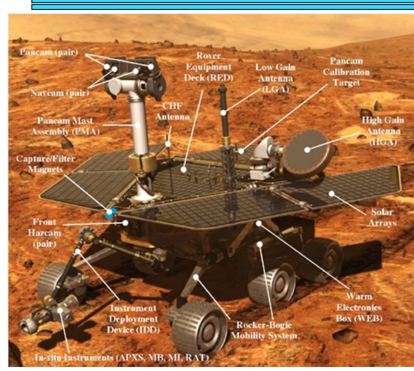
Stanford Cart



MERs

… 1968 — 1976 — … - 2009 …

Mars Exploration Rovers



Sense – Plan – Act "deliberative" architecture

Mars Science Lab

2011 - lasers, lifebio, and maybe nuclear-powered

Robot Architecture

how much / how do we represent the world internally ?

As much as possible!

SPA paradigm

sense → plan → act

Not at all

Reactive paradigm

sense ↔ act

stimulus - response

Task-specific

Behavior-based architecture

As much as *possible*.

Hybrid approaches

Biological Inspiration

Ethology: describing animal behavior

Getting to the ocean?

Digger wasps' nest-building sequence

AI reasoning systems abstract too much away: *frame problem*

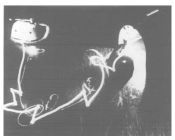
"The world is its own best model"

sense ↔ act

Decision-making is based only on current sensor inputs.

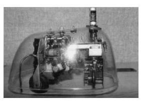
Analog reactive robots

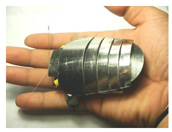
"Tortoise" Gray Walter | Valentino Braitenberg | Mark Tilden (commercial products…) "BEAM"



"light-headed" behavior

http://people.cs.uchicago.edu/~wiseman/vehicles/





http://haroldsbeambugs.solarbotics.net/mercury.htm

robot made from Playstation pieces…!

1951 — 1984 — 1989- …

stateless...

Robot Architecture

how much / how do we represent the world internally ?

As much as possible!

SPA paradigm — sense → plan → act

Not at all

Reactive paradigm — sense ⟷ act

stimulus - response == "behavior"

Task-specific

Behavior-based architecture → Subsumption paradigm, Potential Fields } different ways of composing behaviors

As much as *possible*.

Hybrid approaches

Behavior-based control

Behavior — a direct mapping of sensory inputs to a pattern of task-specific motor actions — sense ⟷ act

"Vertical" task decomposition

extinguish
approach
wander

little explicit deliberation except through system state

SENSING → ACTING

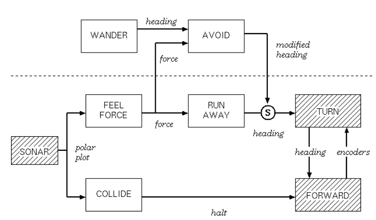
- planning and reasoning
- identify objects
- build maps
- explore
- wander
- avoid objects

Genghis

… 1985 …

Subsumption

- Subsumption builds intelligence incrementally in layers

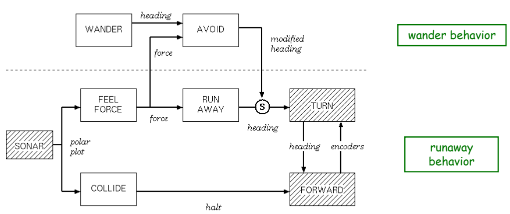


wander behavior

runaway behavior

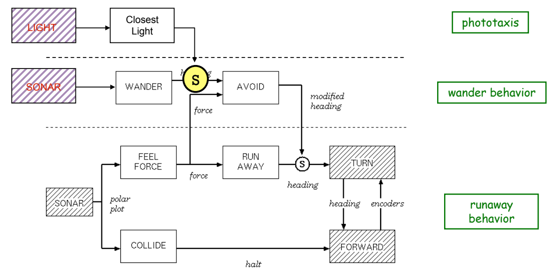
Subsumption

- Where would a light-seeking behavior/layer connect?



Subsumption

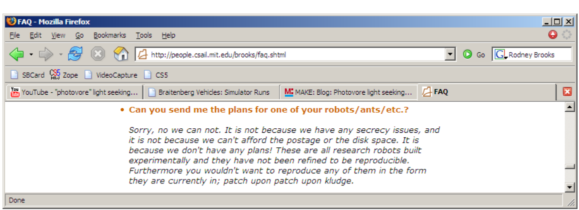
- Where would a light-seeking behavior/layer connect?



Subsumption - Limits

Reaching the end of the subsumption architecture and purely reactive approaches.

Herbert, a soda-can-collecting robot



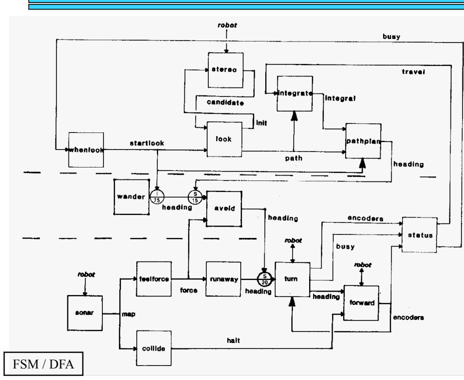
FAQ - Mozilla Firefox

• Can you send me the plans for one of your robots/ants/etc.?

Sorry, no we can not. It is not because we have any secrecy issues, and it is not because we can't afford the postage or the disk space. It is because we don't have any plans! These are all research robots built experimentally and they have not been refined to be reproducible. Furthermore you wouldn't want to reproduce any of them in the form they are currently in; patch upon patch upon kludge.

Success of behavior-based systems depends on how well-tuned they are to their environment. This is a huge strength, but it's also a weakness …

Subsumption *limits*: Genghis



navigate behavior

wander behavior

runaway behavior

FSM / DFA

Unwieldy!

Larger example -- Genghis

1) *Standing* by tuning the parameters of two behaviors: the leg “swing” and the leg “lift”

2) *Simple walking*: one leg at a time

3) *Force Balancing*: via incorporated force sensors on the legs

4) *Obstacle traversal*: the legs should lift much higher if need be

5) *Anticipation*: uses touch sensors (whiskers) to detect obstacles

6) *Pitch stabilization*: uses an inclinometer to stabilize fore/aft pitch

7) *Prowling*: uses infrared sensors to start walking when a human approaches

8) *Steering*: uses the difference in two IR/range sensors to follow

57 modules wired together !

Robot Architecture

how much / how do we represent the world internally ?

As much as possible!

SPA paradigm

sense → plan → act

Not at all

Reactive paradigm

sense ⟷ act

Task-specific

Behavior-based architecture → Subsumption paradigm / Potential Fields } different ways of composing behaviors

As much as *possible*.

Hybrid approaches

Potential Fields

• Potential fields compose simple behaviors by *adding* the outputs that each sensor/input sends the robot

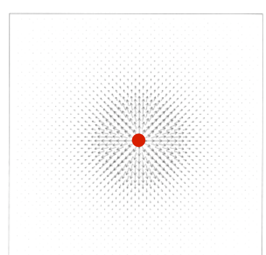
• Individual potential fields (motor schemas) contain state

• A sequencing process (FSM/ DFA) updates the potential fields and/or decides which ones to run next…

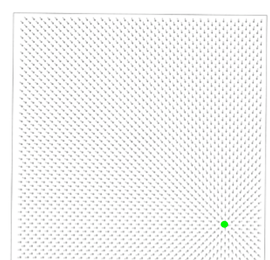
Ron Arkin @ Georgia Tech

Motor Schemas / Potential Fields

Direct mapping from the environment to a control signal



obstacle-avoiding schema

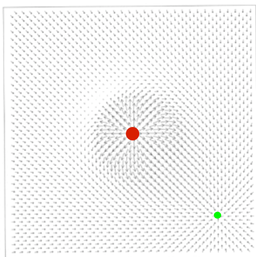


goal-seeking schema

note that the complete environmental vector fields are only for visualization!

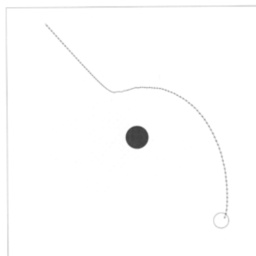
combine?

Behavior Summer

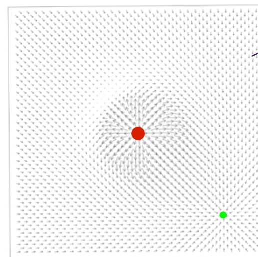


vector sum of the avoid and goal motor schemas

path taken by a robot controlled by the resulting field



Implementation details



the extent to which potential field force drops off with distance…

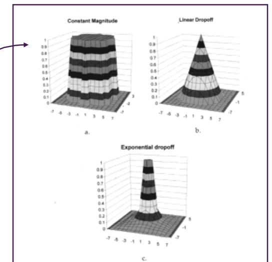
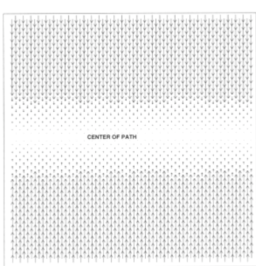


Figure 4.14 Plots of magnitude profiles for a field of radius 5 units: a.) constant magnitude, b.) linear drop off with a slope of -1, and c.) exponential drop off.

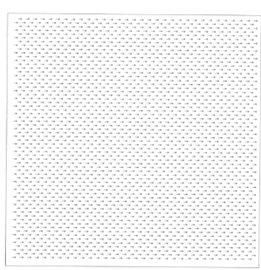
what crucial assumption is being made here?

corridor-following schema(s)?

Additional behavior primitives



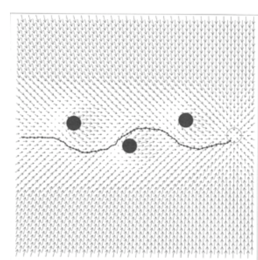
corridor-centering schema



go! schema

A more complex task

Direct mapping from the environment to a control signal



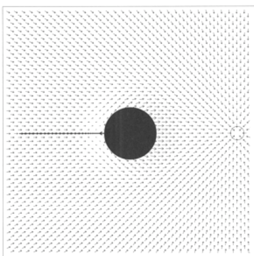
larger composite task

How many individual fields are summed in this task?

Not necessarily all at one time!

Local minima

A potential-field-based system can get stuck!

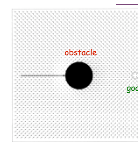


the problem

a solution?

"Potential fields…

Why is the "local minimum" problem, as illustrated to the right, *not* likely to actually cause a robot to get stuck in practice?

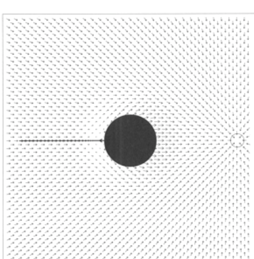


robots controlled by summing goal/obstacle potential fields *can* get stuck in practice -- draw an example of an environment with both obstacle(s) and goals(s) in which getting stuck might actually occur.

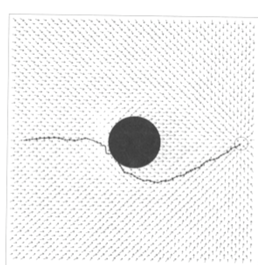
Suggest how a robot might overcome the problem of getting stuck in such cases…

Local minima

A potential-field-based system can get stuck!



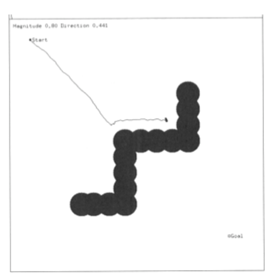
the problem



a solution

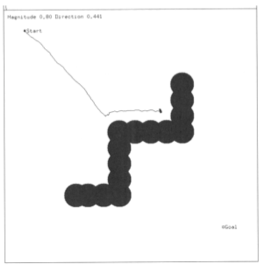
Bigger deadends...

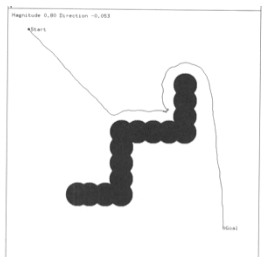
How to get out of larger wells ?



Bigger deadends...

uses memory of where the robot has been

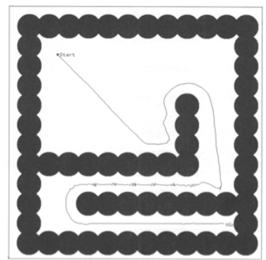


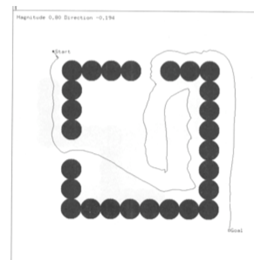


past-avoiding motor schema

Another example

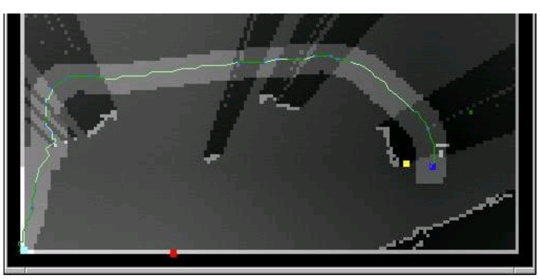
Keeping away from past locations...





Pfields in Practice

Steathy navigation @ USC (Ashley Tews, Gaurav S. Sukhatme, and Maja J. Mataric)



http://robotics.usc.edu/interaction/?l=Research:Projects:stealth:index#experiments

part of the potential field… What's going on here?

Docking with potential fields

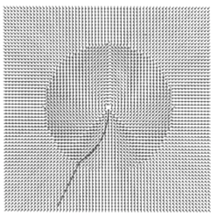
How does the idea of docking, e.g., with an electrical outlet change the requirements for a potential field?

Why might a simple attractive force not be sufficient for docking (plugging-in, etc.)?

example goals

Docking with potential fields

The key insight is the need to establish an approach *direction*



example goals

Figure 4.25 Docking potential field showing path of robot entering from slightly off course.

Docking with potential fields

The key insight is the need to establish an approach *direction*

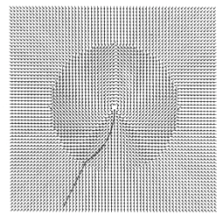


Figure 4.25 Docking potential field showing path of robot entering from slightly off course.

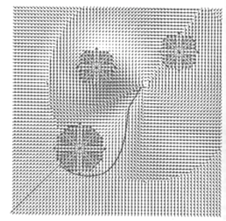


Figure 4.26 Visualization of the docking behavior with obstacles.

+ Review

- HMMs
  - What are they?
    - Markov assumption
    - what are the probabilities we model
  - Different problems/questions (filtering, prediction, smoothing, most likely explanation/Viterbi)
  - Applications

+ Review

- Machine learning
  - general learning concepts
    - supervised vs. unsupervised
    - features/feature-based problems/feature space
    - bias/variance
    - overfitting
    - hyperplanes/linear seperability
  - Supervised learning
    - applications
    - approaches
      - k-NN
      - decision trees
      - NB
      - SVM (large margin classifiers)
      - decision stumps
    - Ensemble approaches (boosting)

+ Review

- Machine learning (continued)
  - unsupervised learning
    - application
    - issues
      - number of clusters
      - flat vs. hierarchical
      - soft vs. hard clustering
    - approaches
      - k-means
      - EM
        - word alignment
        - clustering (mixture of gaussians)
      - spectral clustering (min-cut)

+ Review

- Neural networks (Machine learning?)
  - perceptrons/neurons
    - activation functions (threshold vs. sigmoid)
    - perceptron learning
  - multi-layer networks
    - backpropogation algorithm
- Knowledge representation
  - basic logic
  - ontology
  - NELL

+ Review

- Computer vision
  - Applications
  - Problem areas
  - Convolution features
  - Eigenfaces algorithm
- Robotics (won't be on the final)

+ Guest speaker

- Rodney Brooks
  - Professor at MIT (was previous director of CSAIL)
  - Founder of iRobot
- http://www.youtube.com/watch?v=B79D9nW2AFA