Behavior-Based Control

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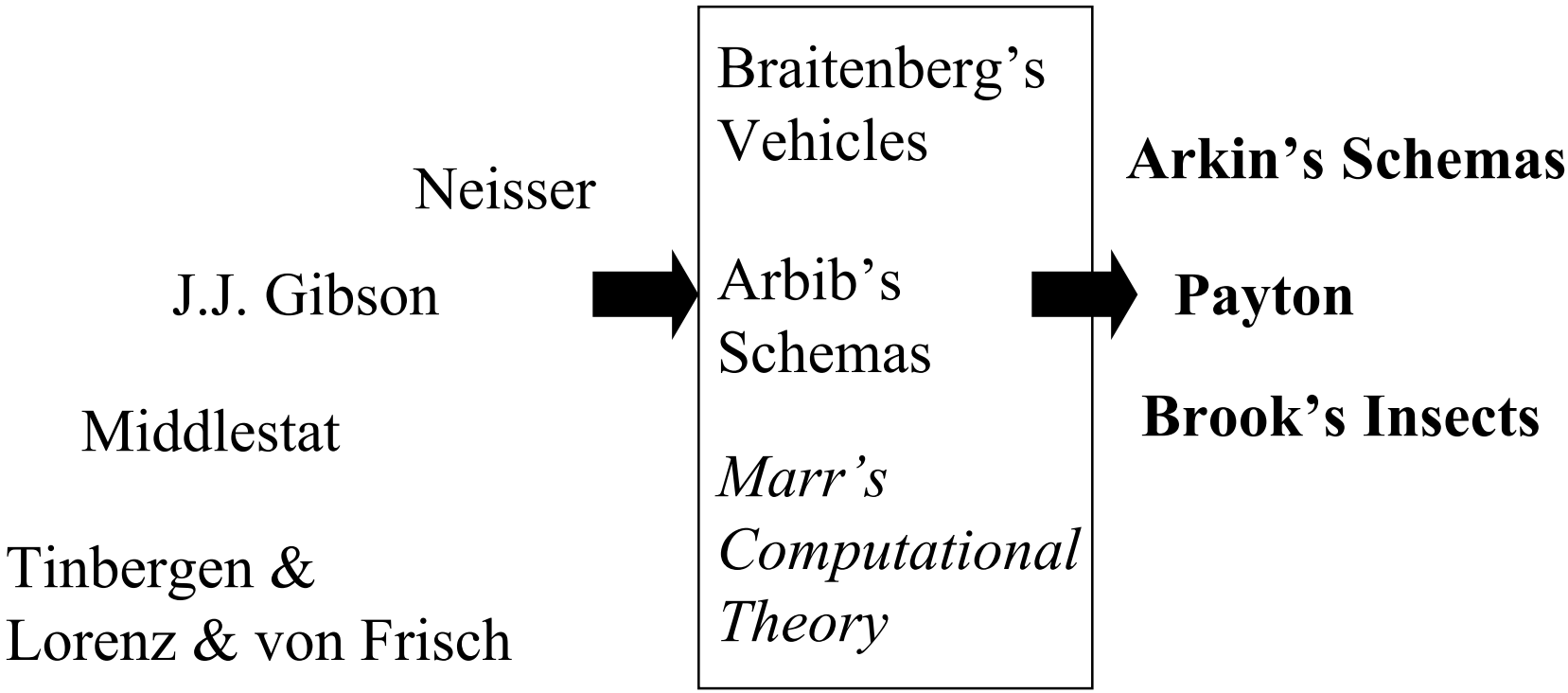
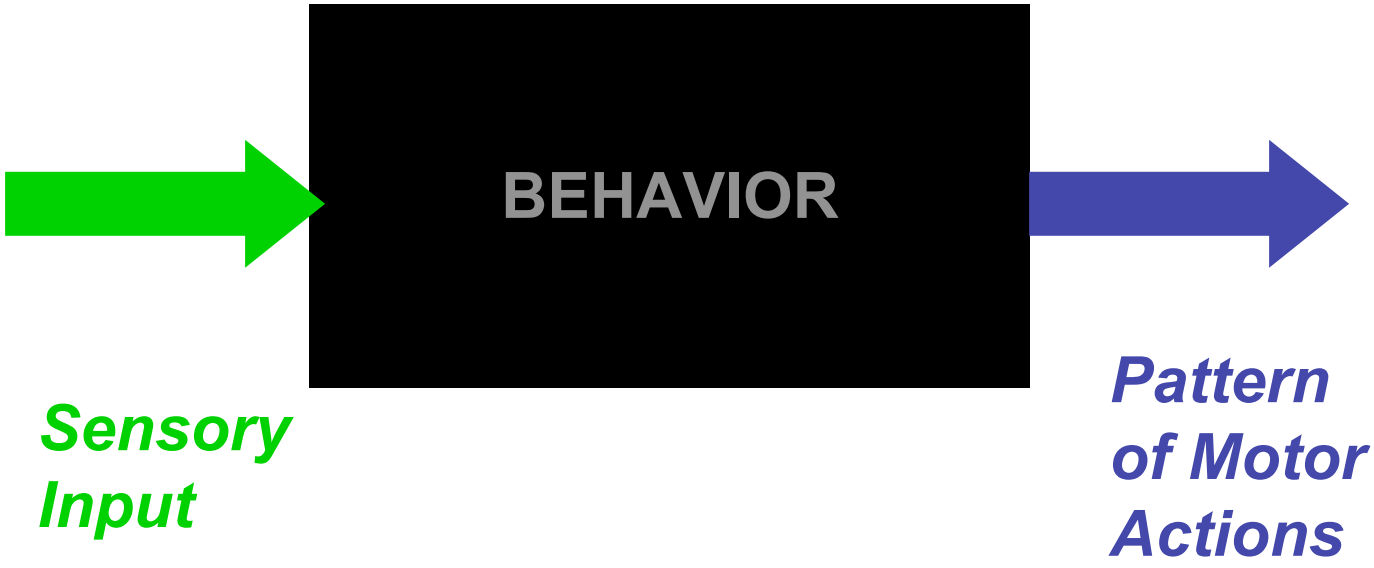
Most slides adapted from Tucker Balch or Robin Murphy's publicly available slides (http://www.cse.usf.edu/~murphy/book/)

Timeline of Influences



Behavior Definition (graphical)



Types of Behaviors

- **Reflexive**
  - stimulus-response, often abbreviated S-R
- **Reactive**
  - learned or “muscle memory”
- **Conscious**
  - deliberately stringing together

WARNING Overloaded terms:
Roboticists often use “reactive behavior” to mean purely reflexive,
And refer to reactive behaviors as “skills”

Ethology: Coordination and Control of Behaviors

Nobel 1973 in physiology or

INNATE RELEASING MECHANISMS

- Lorenz
- Tinbergen

www.nobel.se

Arctic Terns

- Arctic terns live in Arctic (black, white, gray environment, some grass) but adults have a red spot on beak

- When hungry, baby pecks at parent's beak, who regurgitates food for baby to eat

- How does it know its parent?
  - It doesn't, it just goes for the largest red spot in its field of view (e.g., ethology grad student with construction paper)
  - **Only red thing should be an adult tern**
  - **Closer = large red**

Example: Cockroach Hide

- light goes on, the cockroach turns and runs
- when it gets to a wall, it follows it
- when it finds a hiding place (thigmotrophic), goes in and faces outward
- waits until not scared, then comes out
- *even if the lights are turned back off earlier*

Gibson's Ecological Approach

- *Acting* and *sensing* co-evolved as agent survived in a particular *environment.* The environment *affords* the agent what it needs to survive.

- The perception needed to release or guide the "right action" is directly in the environment, not inferred or memorized
  - Ex. Red on Artic Terns== food
  - Ex. Sound of filling container==full

- Percepts are called *affordances* or said to be obtained through *direct perception*

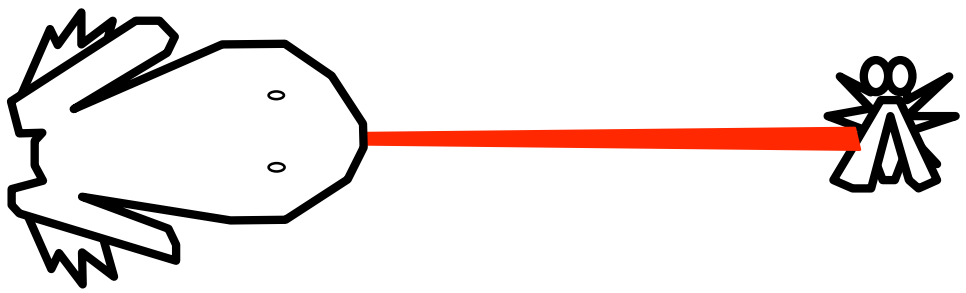
Gibsonian Affordances

- How do you know you're going fast in a car? Or in a space movie?
- How do animals know when to mate?
- How do mosquitoes know to bite in the most tender areas?
- What should you do when you think you're being stalked by a mountain lion?
- What's your favorite fishing lure?

Motor Schemas

Behavior-Based Architectures: Motor Schemas

- Multiple independent processes each generate a vector combined by weighted summation
- Computationally simple and fast
- Enables design by composition. Related to artificial potential fields
  - Khatib, Krogh, Payton, Singh



Definition 1: Reactive

"A ***reactive*** robotic system tightly couples perception to action without the use of intervening abstract representations or time history." --Ron Arkin

Definitions: Behavior-Based

A ***behavior-based*** robotic system generally relies on a tight stimulus-response framework, but may utilize minimal state information as well. --Tucker Balch

Example 1: Robomow

- Behaviors?
- Random
- Avoid
  - Avoid(bump=obstacle)
  - Avoid(wire=boundary)
- Stop
  - Stop(tilt=ON)
- All active

Example 2: My Real Baby

- Behaviors?
- Touch-> Awake
- Upside down & Awake-> Cry
- Awake & Hungry -> Cry
- Awake & Lonely -> Cry

- *Note can get crying from multiple behaviors*
- *Note internal state (countdown timer on Lonely)*

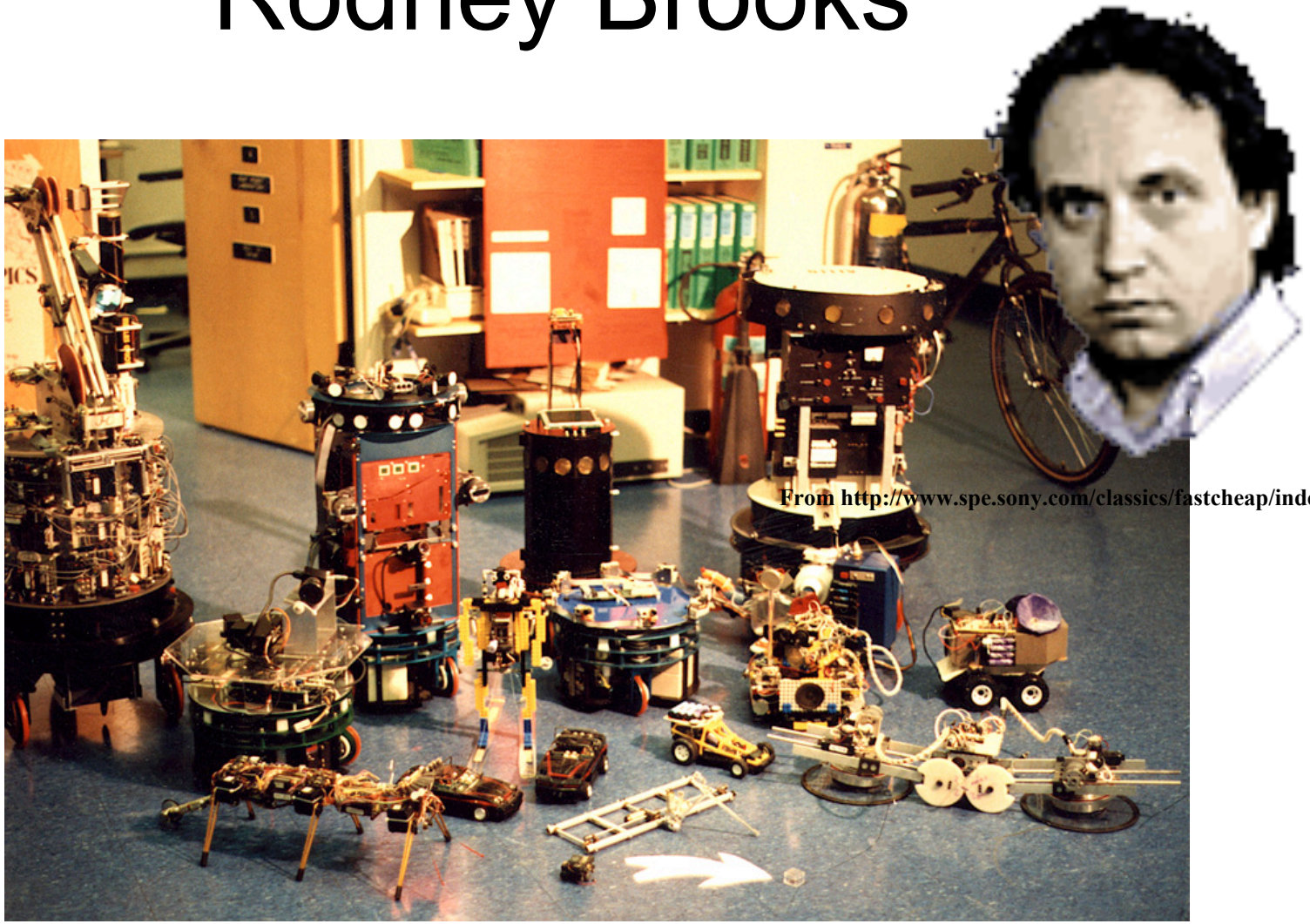
Reactive

- Historically, there are two main styles of creating a reactive system
  - Subsumption architecture
    - Layers of behavioral competence
    - How to control relationships
  - Potential fields
    - Concurrent behaviors
    - How to navigate
- They are equivalent in power
- In practice, see a mixture of both layers and concurrency

Influential Architectures

- Subsumption -- Brooks, 1986
- Motor schemas -- Arkin, 1987
- Distributed Architecture for Mobile Navigation (DAMN) -- Rosenblatt, 1989
- Colony Architecture -- Connell, 1989
- Reactive Action Packages (RAPs) -- Firby, 1989

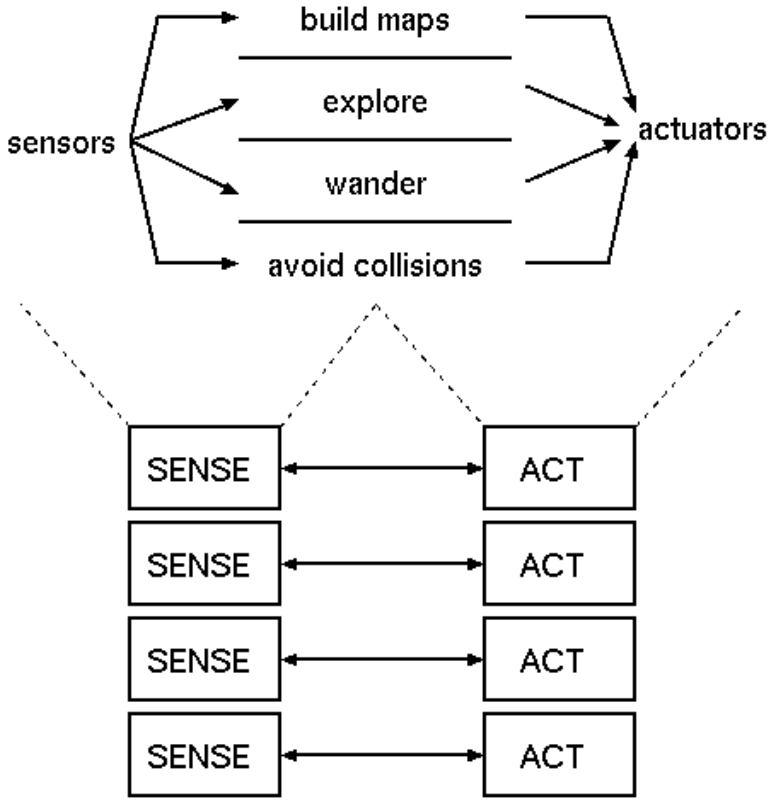
Subsumption: Rodney Brooks



From http://www.spe.sony.com/classics/fastcheap/index.html

Subsumption Philosophy

- Modules should be grouped into *layers of competence*
- Modules in a higher lever can override or *subsume* behaviors in the next lower level
  - Suppression: substitute input going to a module
  - Inhibit: turn off output from a module
- ***No internal state*** in the sense of a local, persistent representation similar to a world model.
- Architecture should be *taskable*: accomplished by a higher level turning on/off lower layers

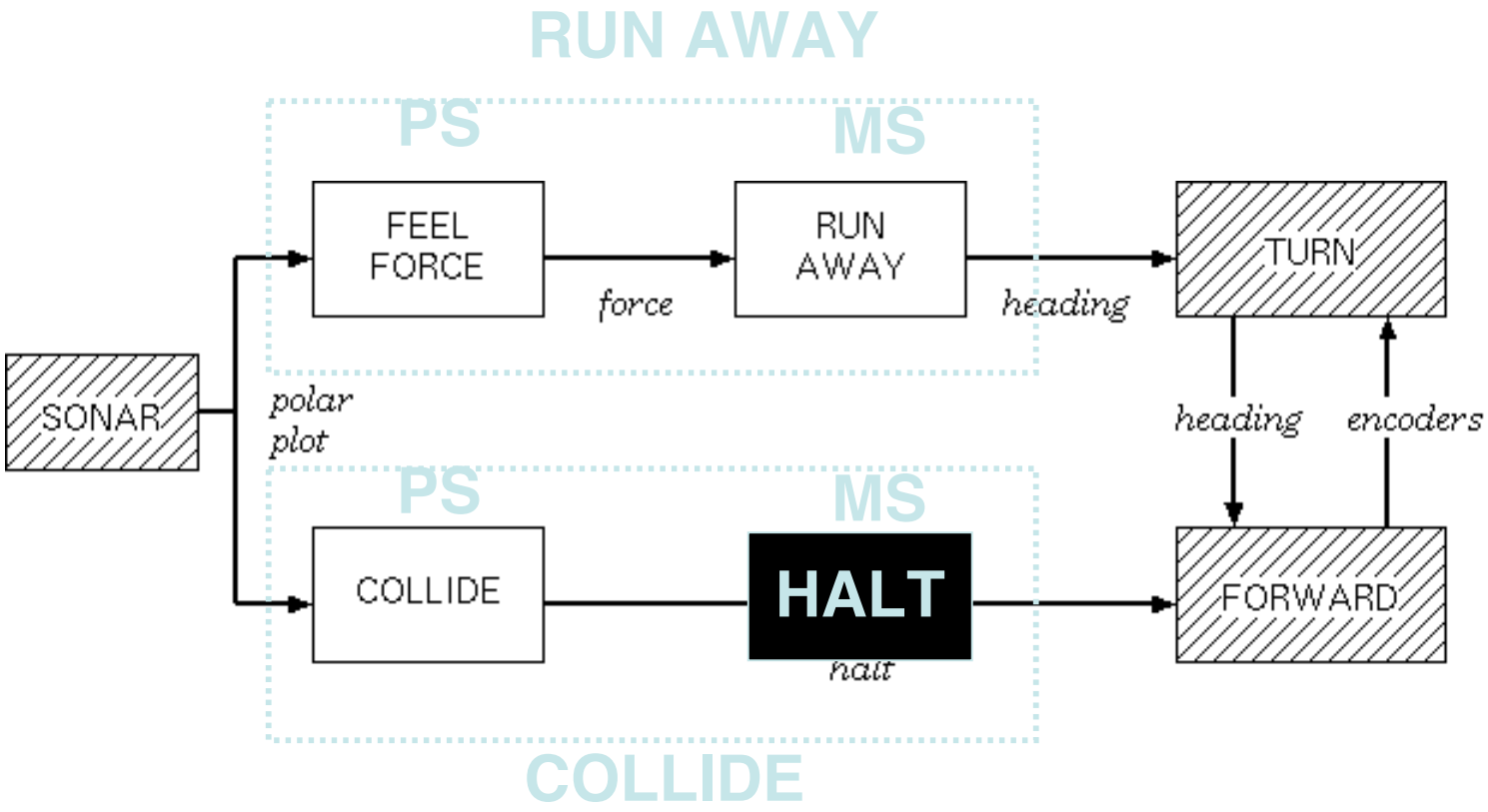


Level 0: Runaway

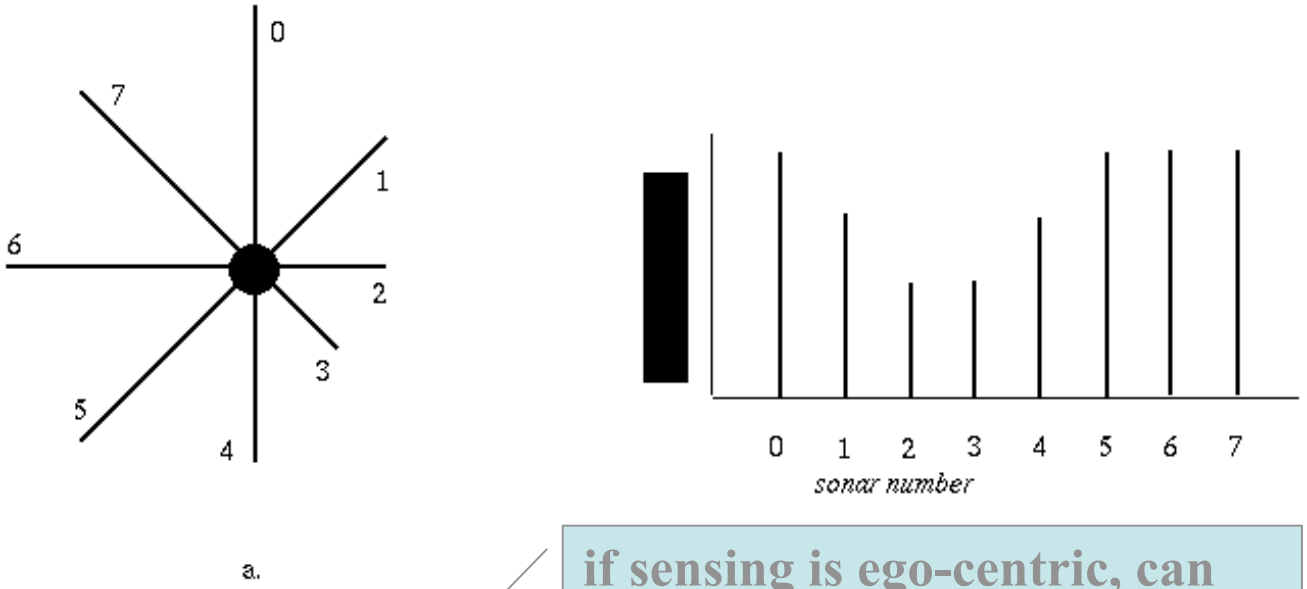
follow-corridor 2

wander 1

runaway 0



Example Perception: Polar Plot



a.

if sensing is ego-centric, can often eliminate need for memory, representation

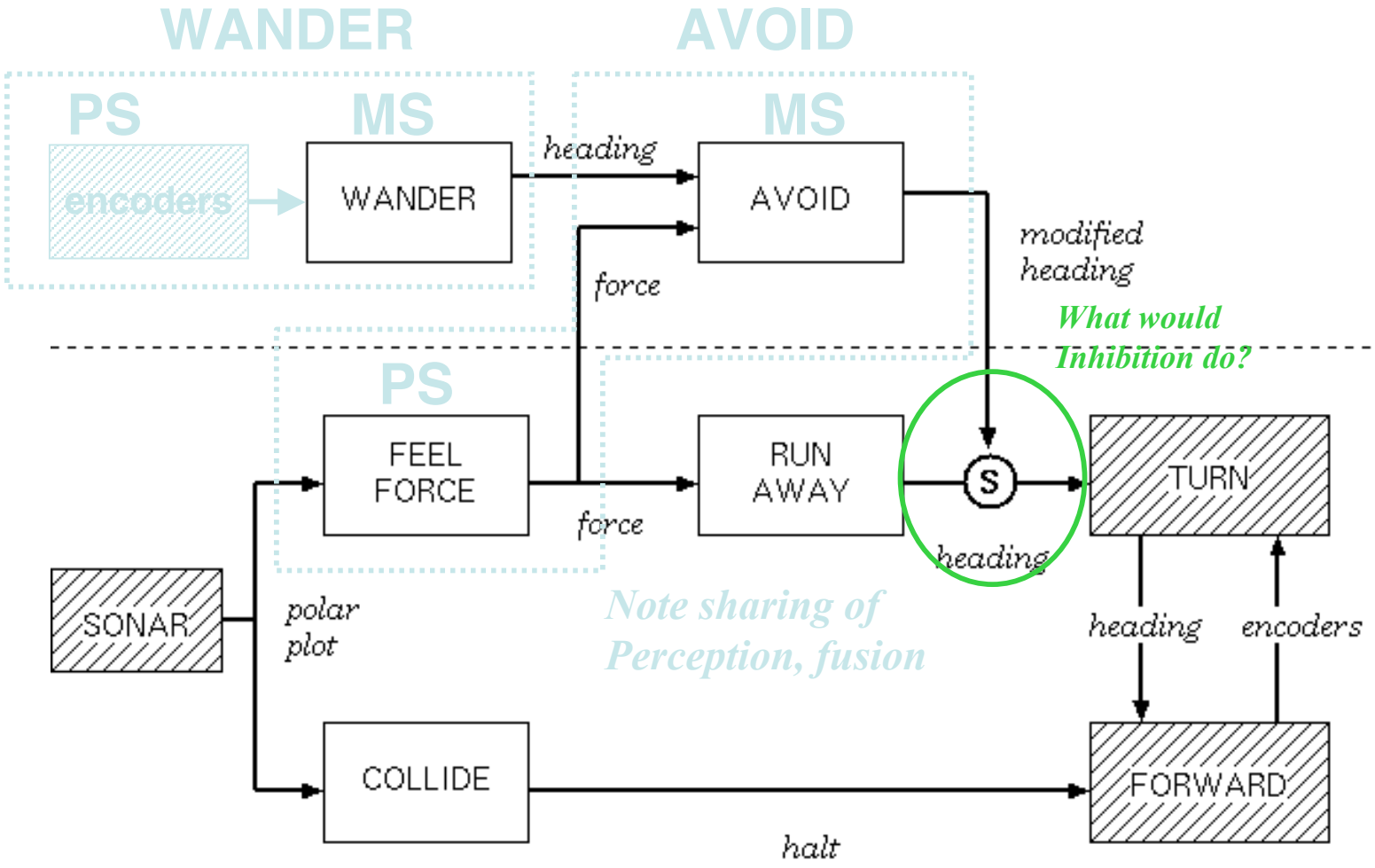
- Plot is *ego-centric*
- Plot is distributed (available to whatever wants to use it)
- Although it is a representation in the sense of being a data structure, there is no memory (contains latest information) and no reasoning (2-3 means a “wall”)

Level 1: Wander

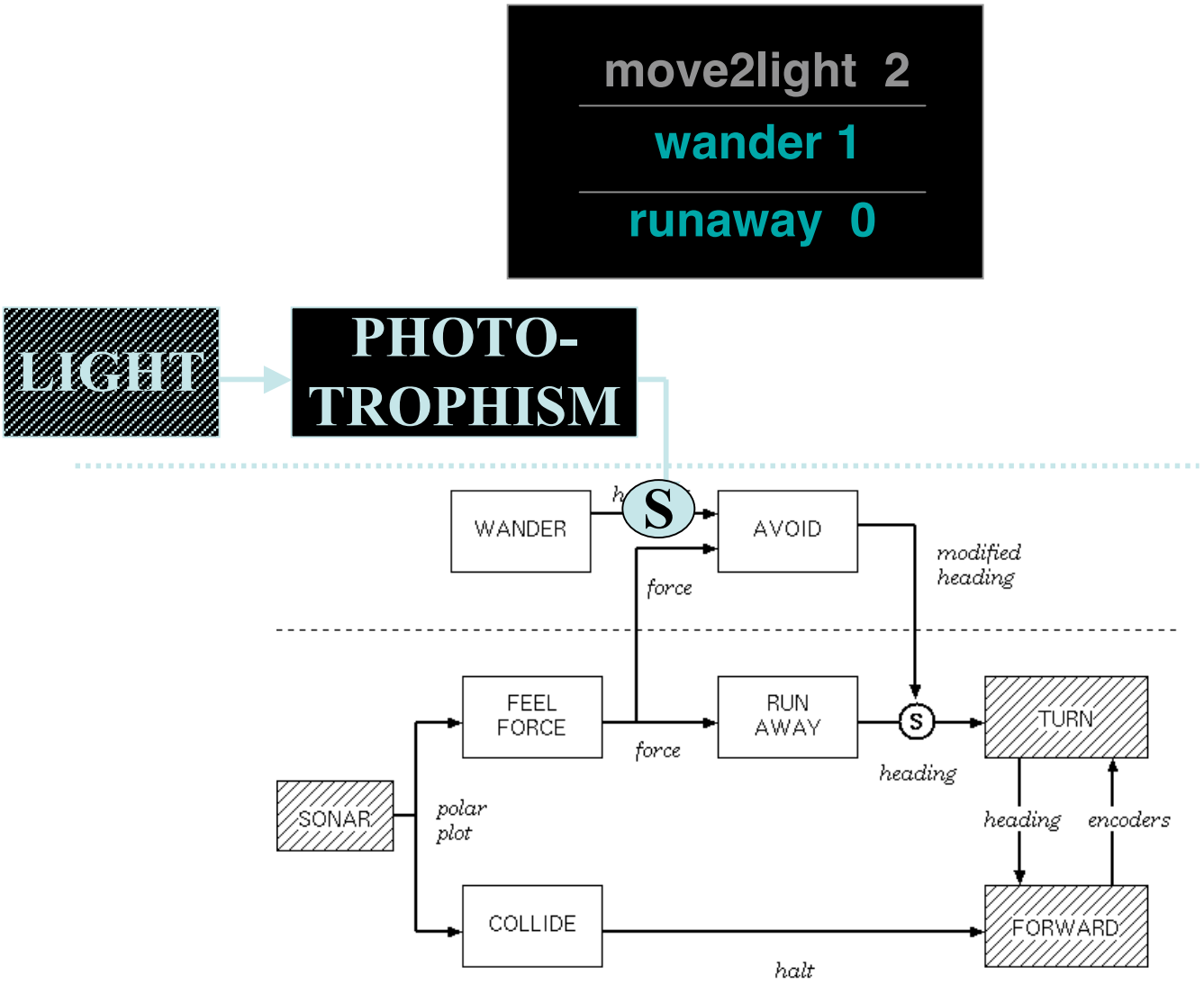
follow-corridor 2

wander 1

runaway 0



Moving to Light

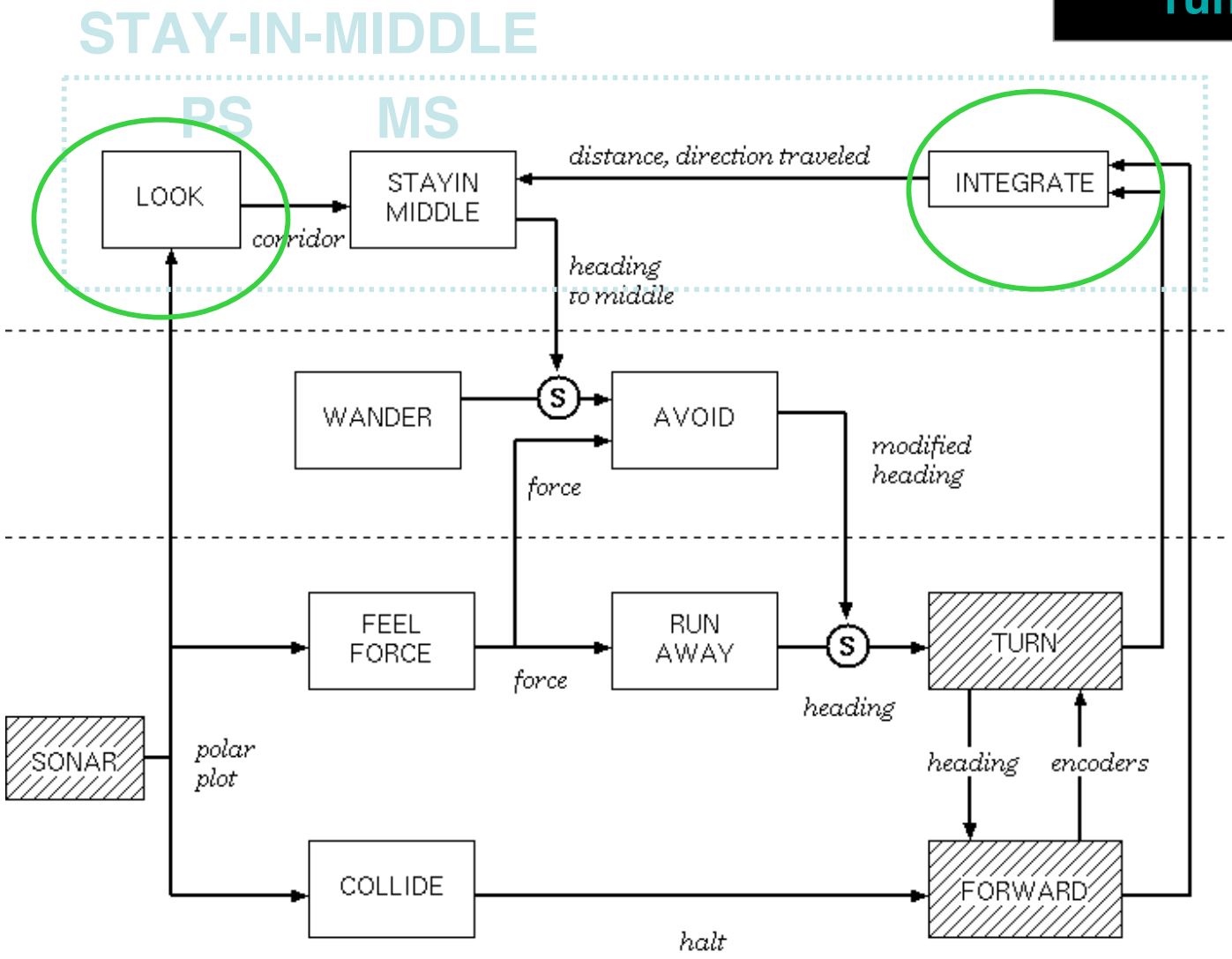


Follow-Corridors

follow-corridor 2

wander 1

runaway 0



Potential Fields: Ron Arkin

From http://www.cc.gatech.edu/aimosaic/faculty/arkin

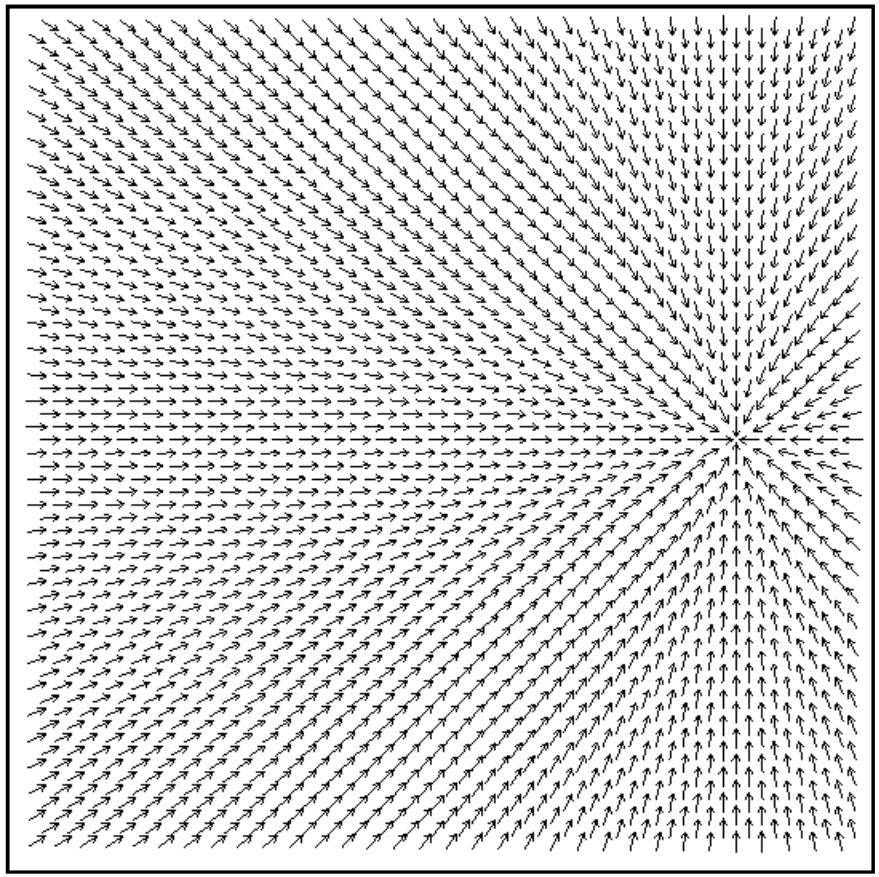
From http://www.cc.gatech.edu/aimosaic/robot-lab/MRLhome.html

Potential Fields Philosophy

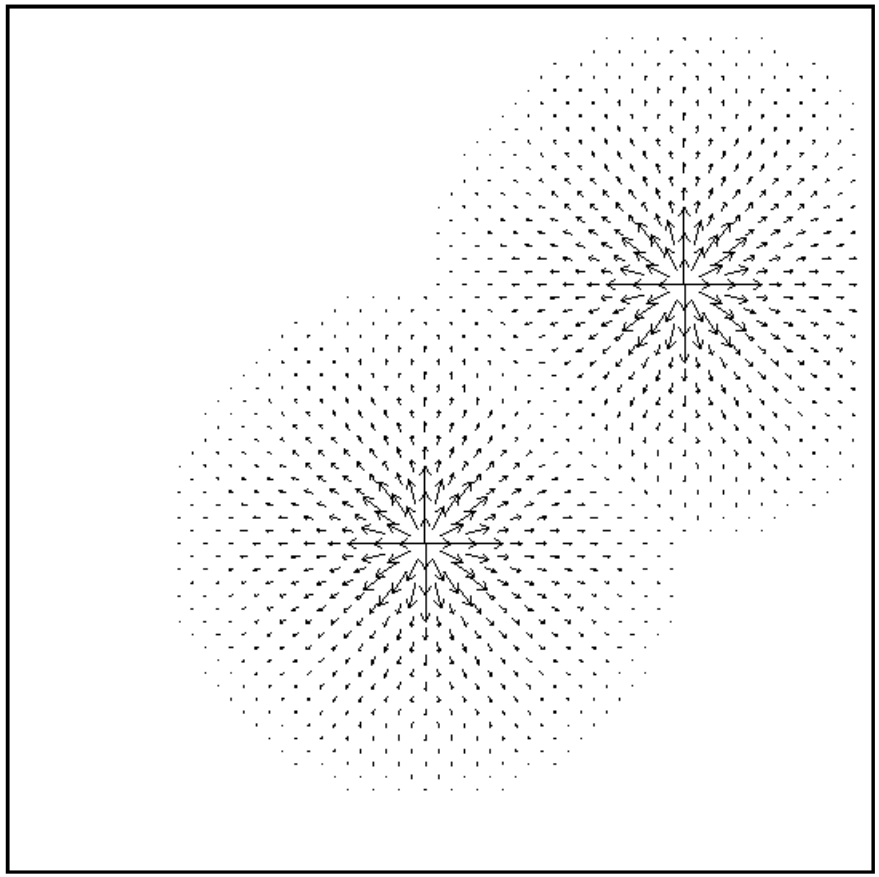
- The motor schema component of a behavior can be expressed with a potential fields methodology
  - A potential field can be a “primitive” or constructed from primitives which are summed together
  - The output of behaviors are combined using vector summation
- From each behavior, the robot “feels” a vector or force
  - Magnitude = force, strength of stimulus, or *velocity*
  - Direction
- But we visualize the “force” as a field, where every point in space represents the vector that it would feel if it were at that point

Primitive: Move to Goal

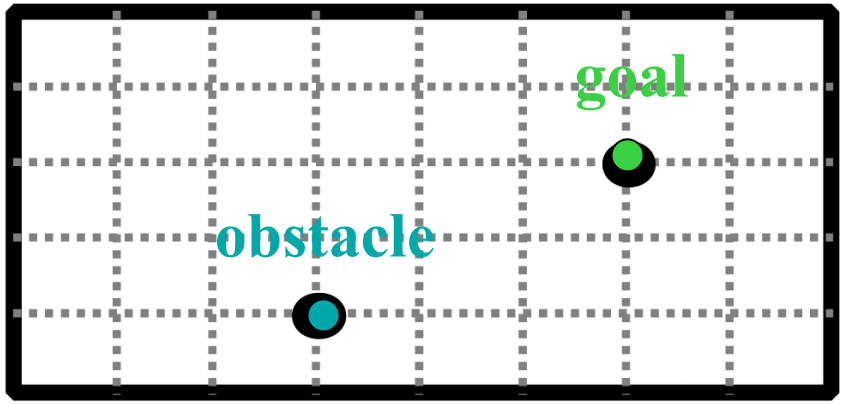
Behavior-Based Architectures: Motor Schemas

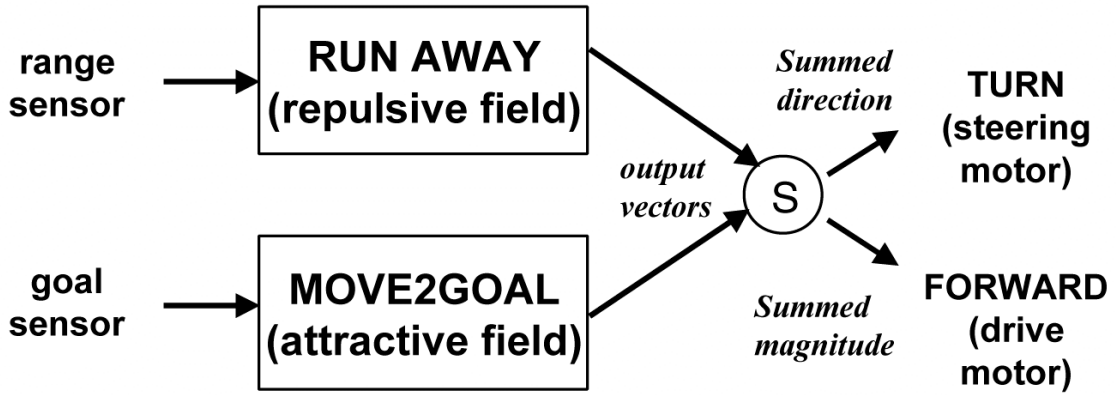


Primitive: Avoid Obstacle

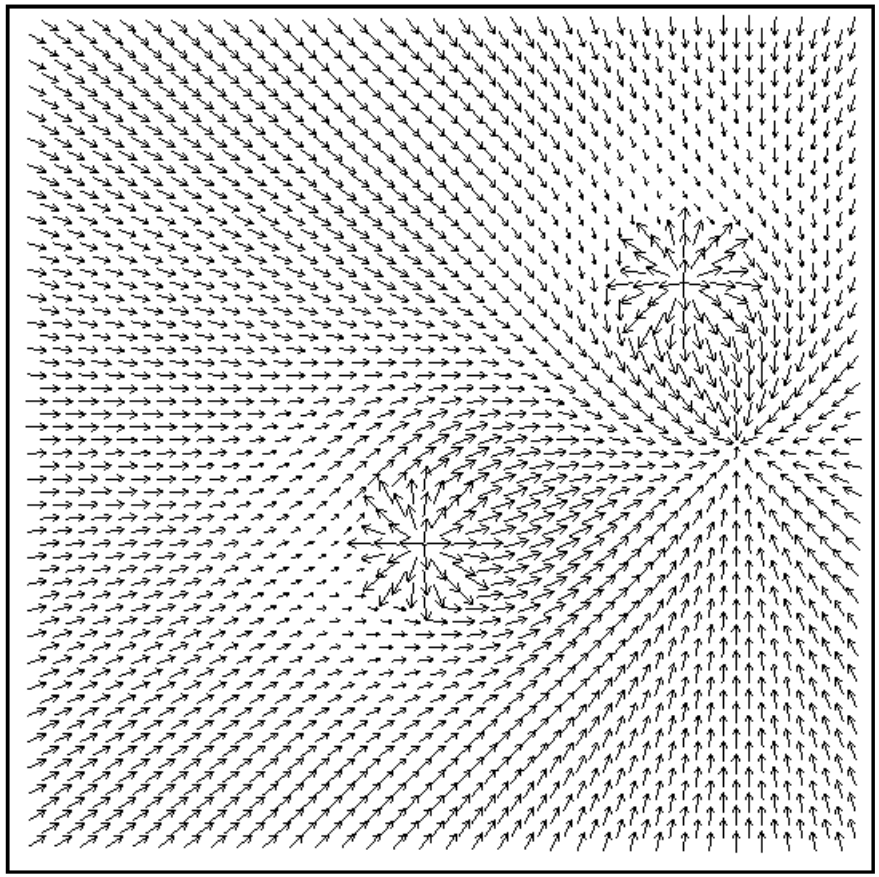


Combining Fields for Emergent Behavior

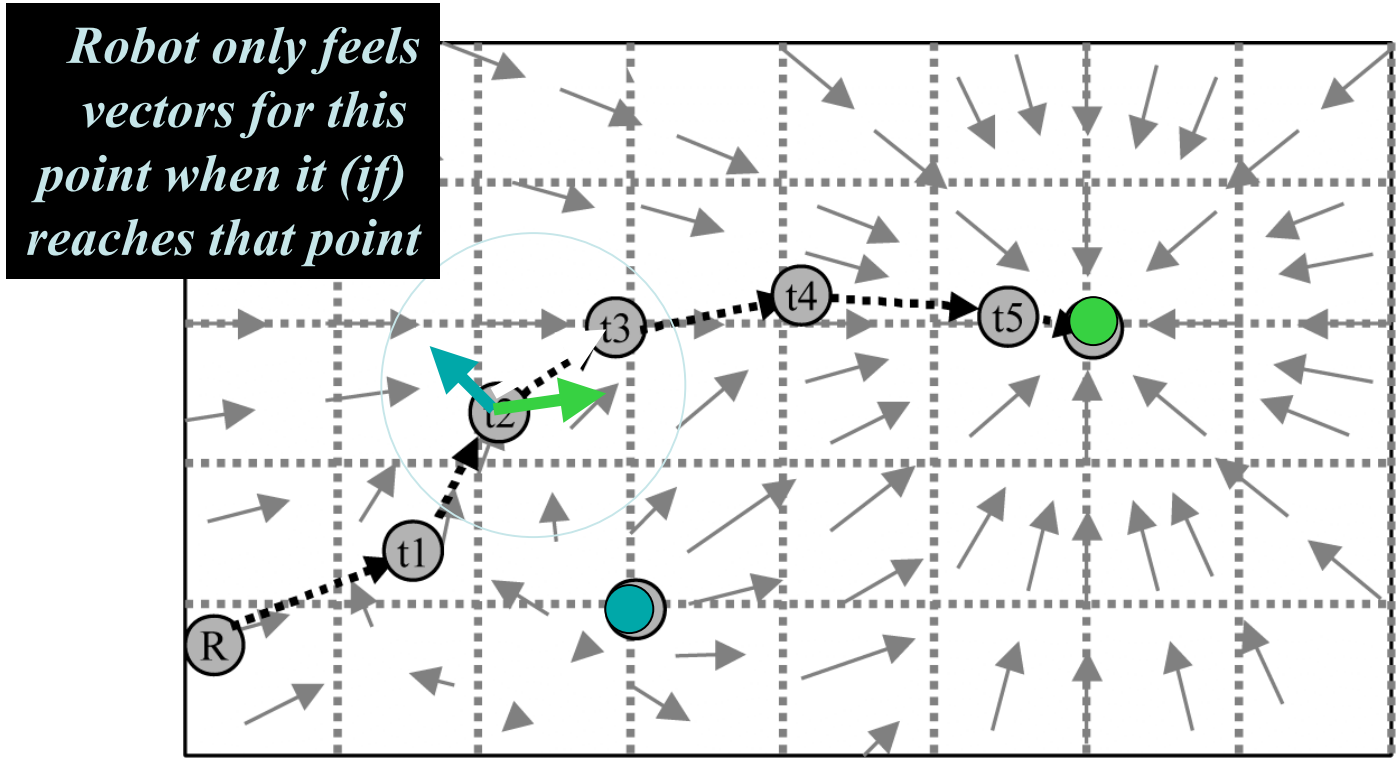




Avoid Obstacle + Move to Goal

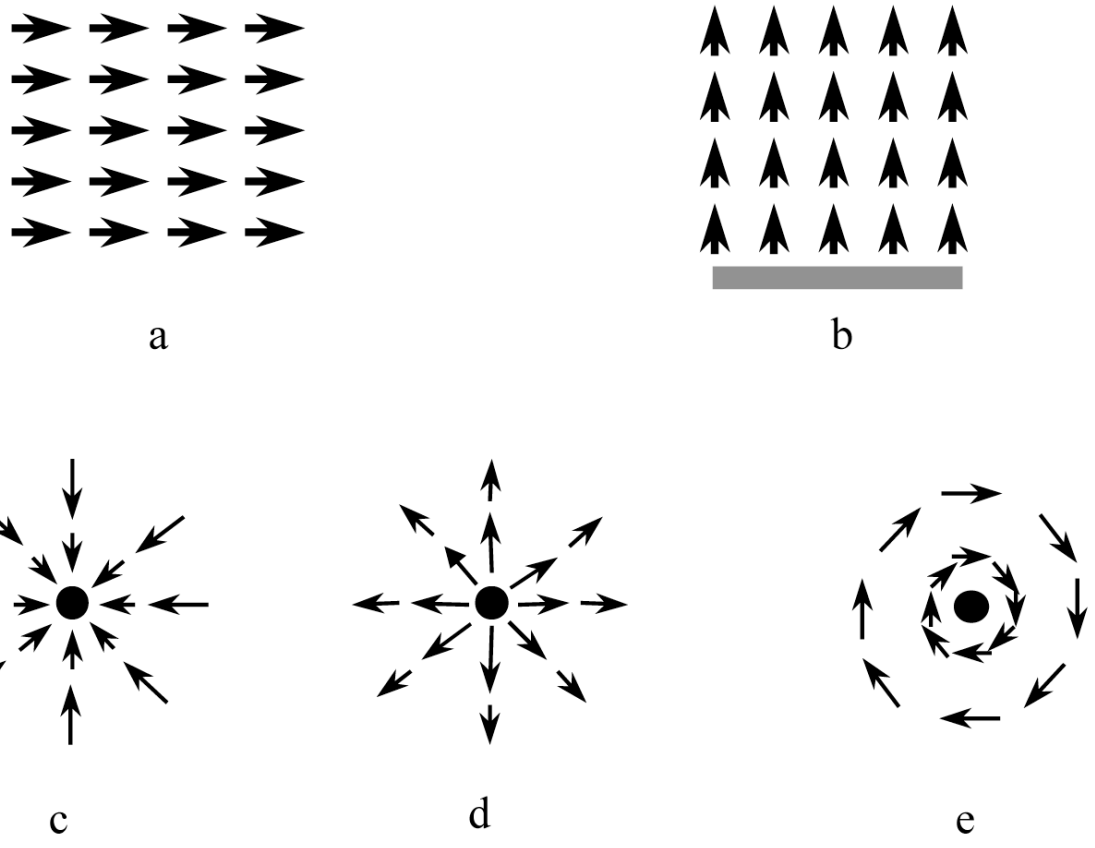


Path Taken

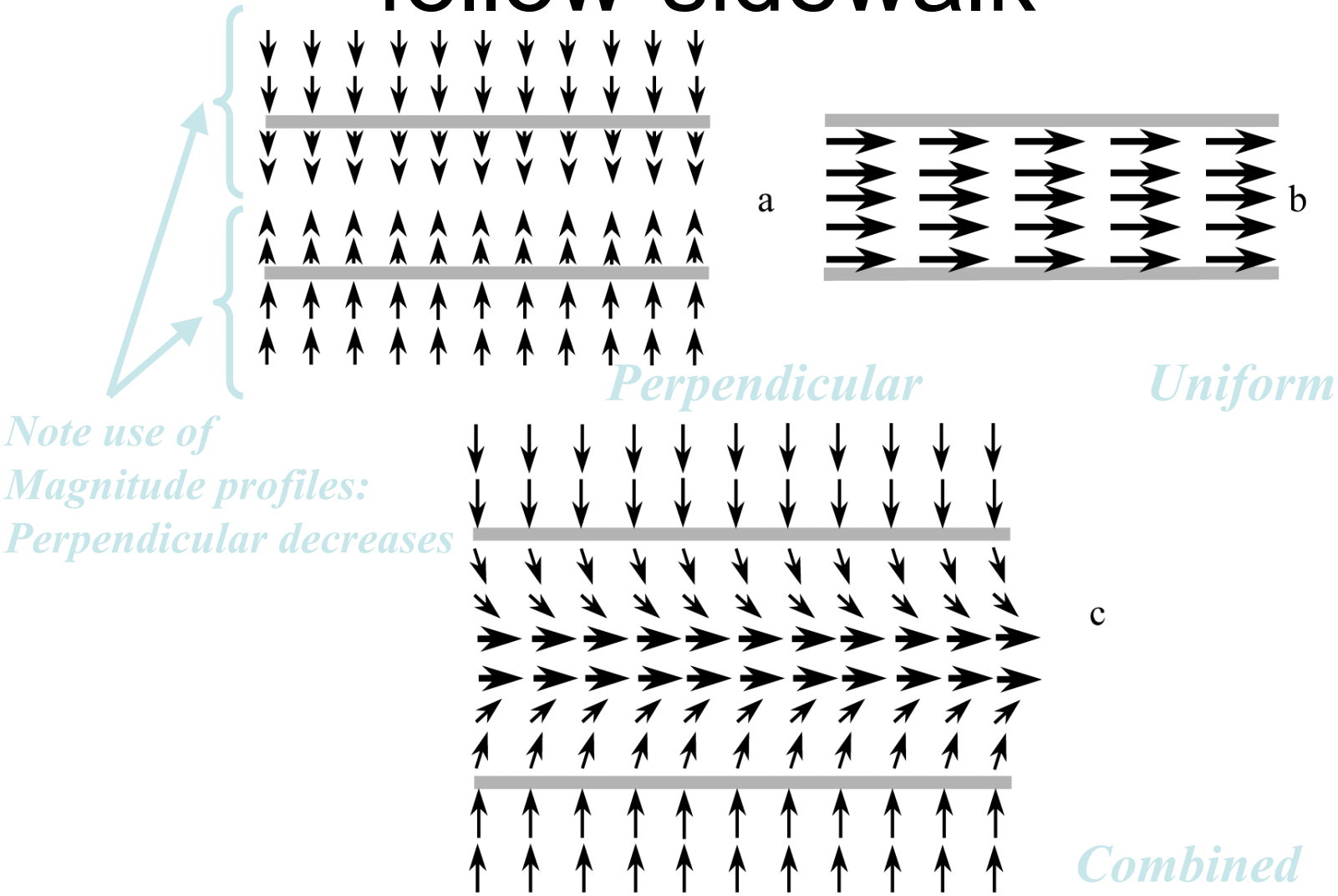


- If robot started at this location, it would take the following path
- It would only “feel”the vector for the location, then move accordingly, “feel” the next vector, move, etc.
- Pfield visualization allows us to see the vectors at all points, but robot never computes the “field of vectors” just the local vector

5 Primitive Potential Fields

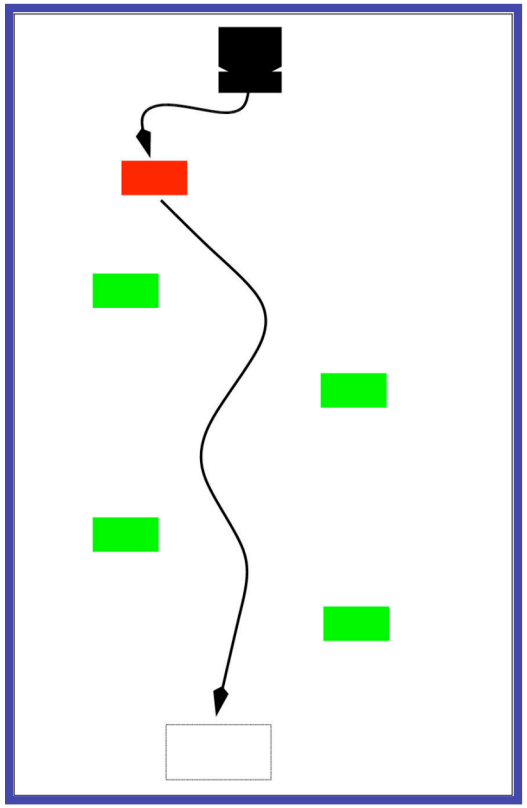


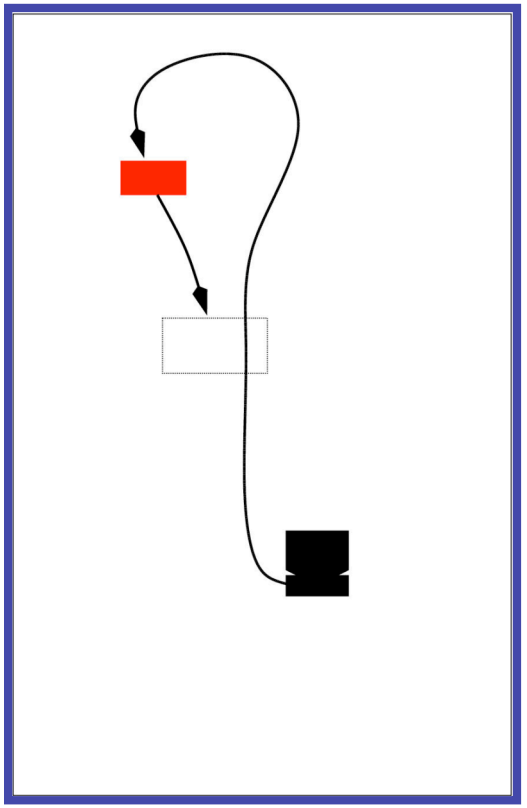
Example: follow-corridor or follow-sidewalk



More Complex Problem: Pushing

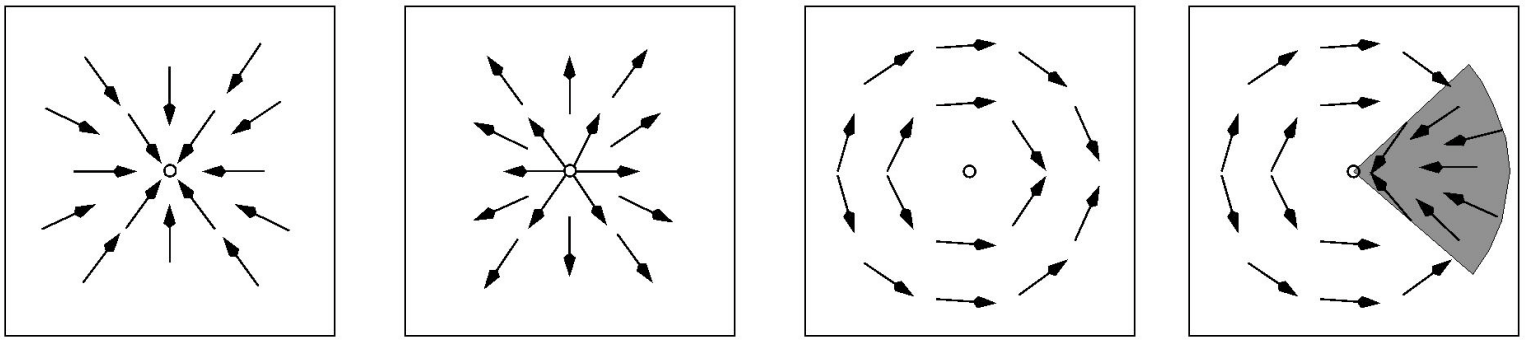
Behavior-Based Architectures: Motor Schemas





Approach: Specialized Schemas

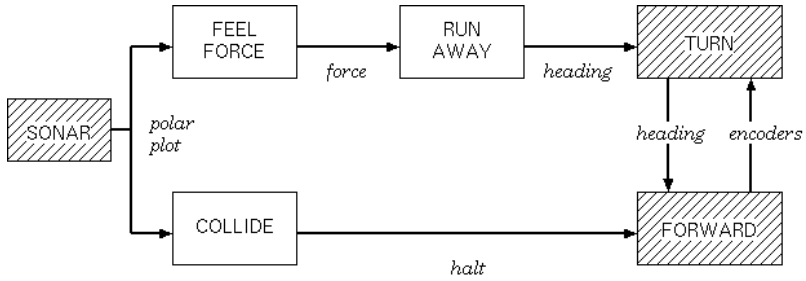
Behavior-Based Architectures: Motor Schemas

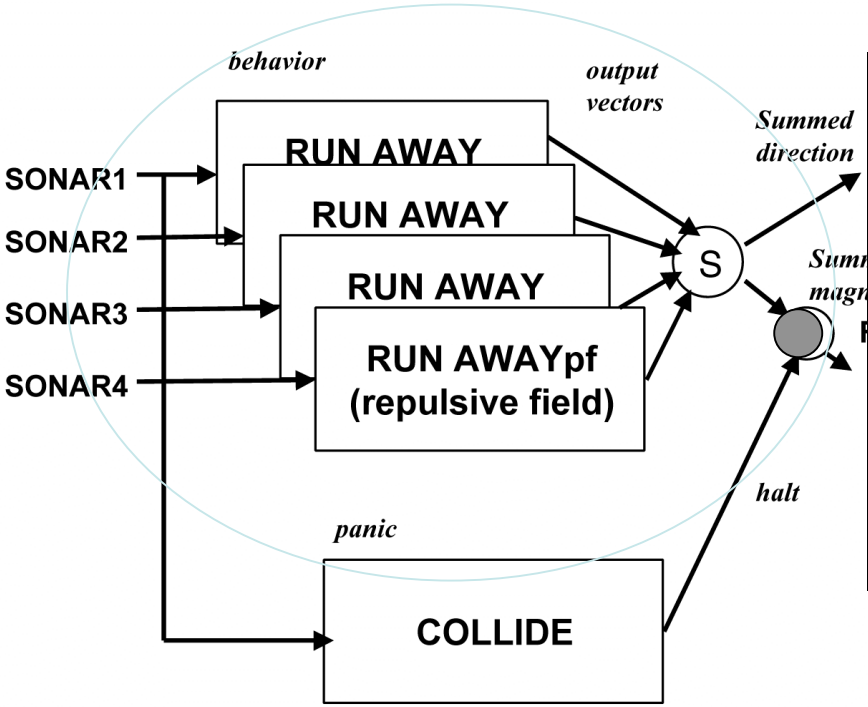


Video: Pushing

Behavior-Based Architectures: Motor Schemas

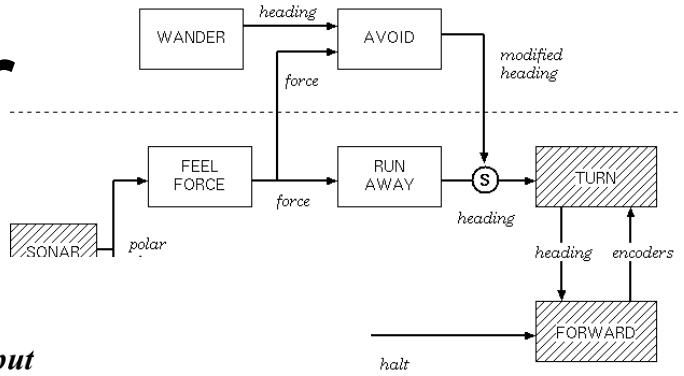
Level 0: Runaway



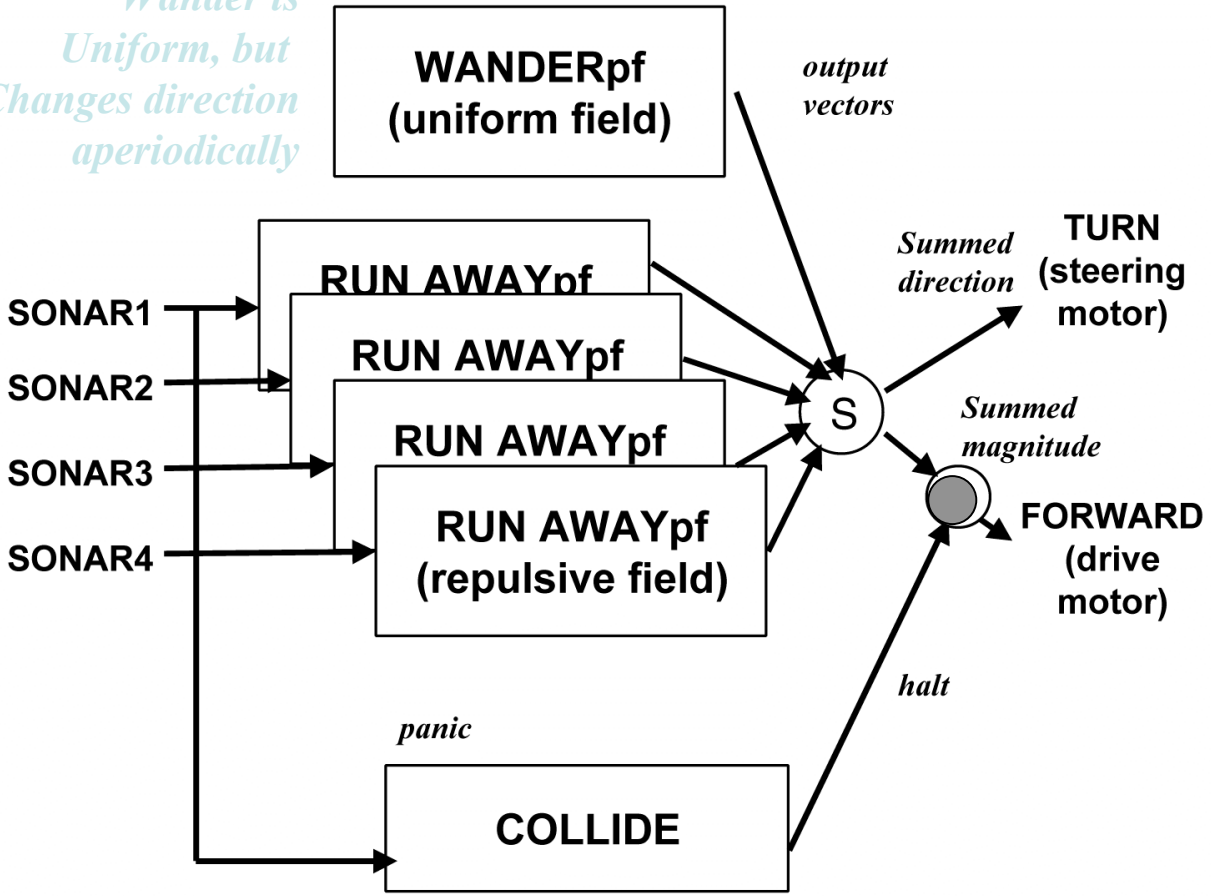


Note: multiple instances of a behavior vs. 1:
Could just have 1 Instance of RUN AWAY, Which picks nearest reading; Doesn't matter, but this Allows addition of another Sonar without changing the RUN AWAY behavior

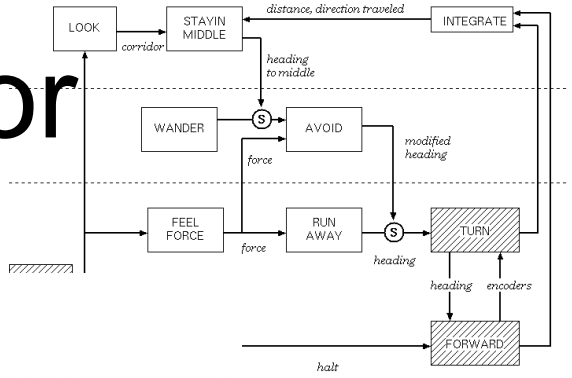
Level 1: Wander

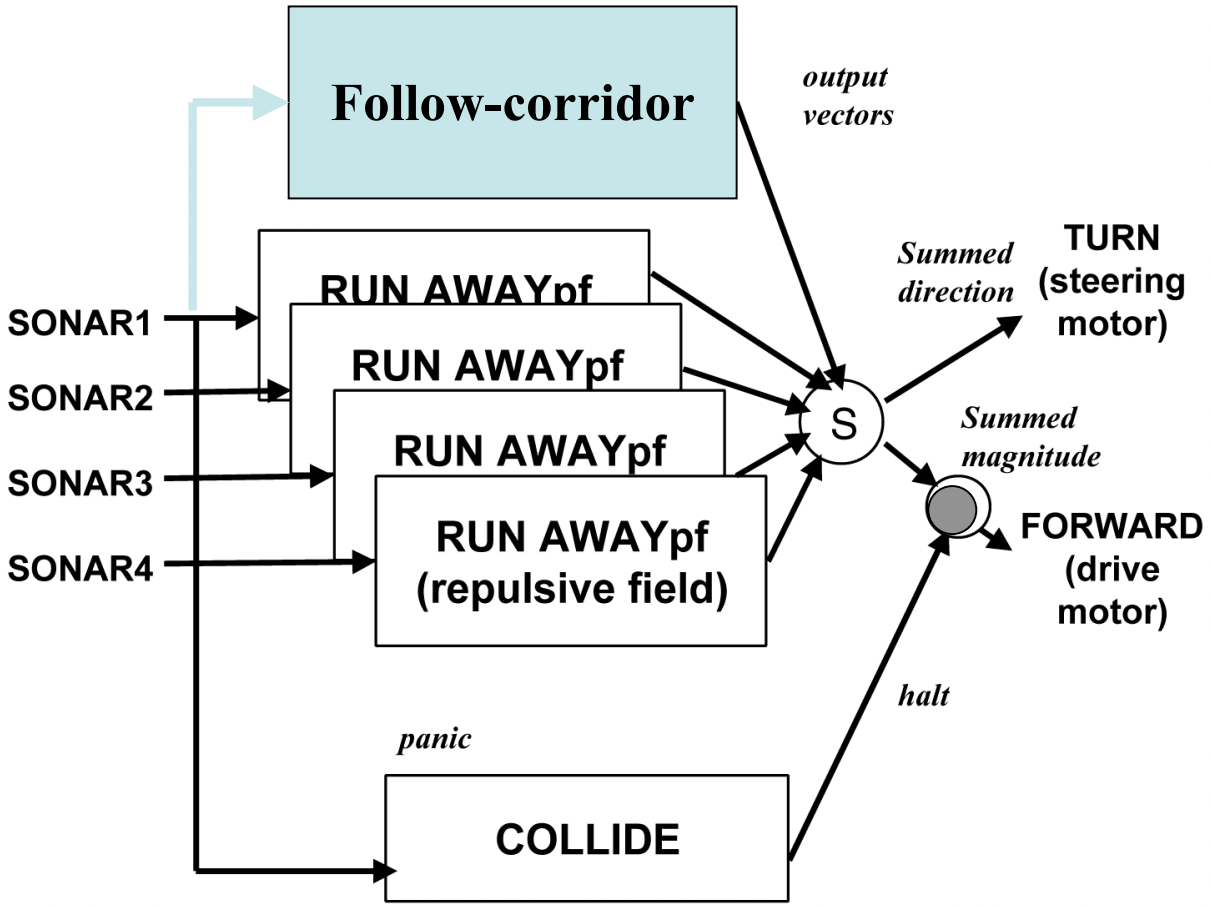


Wander is Uniform, but Changes direction aperiodically



Level 2: Follow Corridor



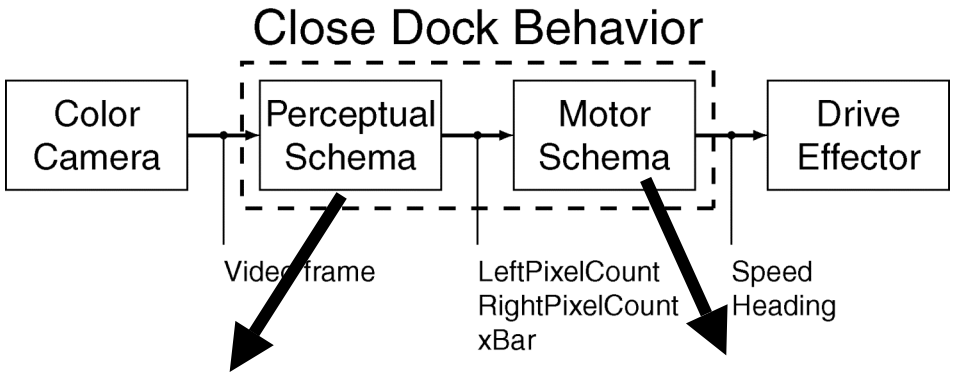


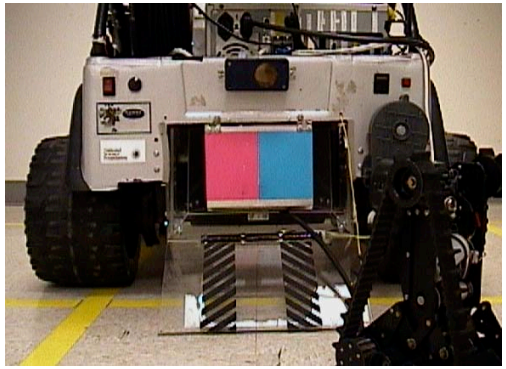
Should we Leave Run Away In? Do we Need it?

Potential fields

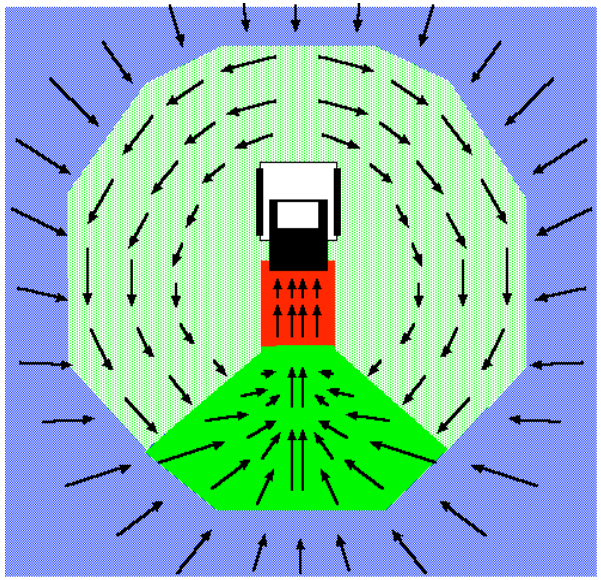
- Advantages
  - Easy to visualize
  - Easy to build up software libraries
  - Fields can be parameterized
  - Combination mechanism is fixed, tweaked with gains
- Disadvantages
  - Local minima problem (sum to magnitude=0)
    - Box canyon problem
  - Jerky motion

Example: Docking Behavior





Orientation, ratio of pixel counts →
tangent vector
Total count →
attraction vector



•Arkin and Murphy, 1990, Questa, Grossmann, Sandini, 1995, Tse and Luo, 1998, Vandorpe, Xu, Van Brussel, 1995. Roth, Schilling, 1998, Santos-Victor, Sandini, 1997

Docking Behavior Video

Docking Behavior Video 2

Behavior-Based Summary

- Reactive Paradigm: SA, sensing is local
  - Solves the *Open World problem* by emulating biology
  - Perception is direct, ego-centric, and distributed
- Two architectural styles are: *subsumption* and *pfields*
- Behaviors in pfield methodologies are a tight coupling of sensing to acting; modules are mapped to schemas conceptually
- Potential fields and subsumption are logically equivalent but different implementations