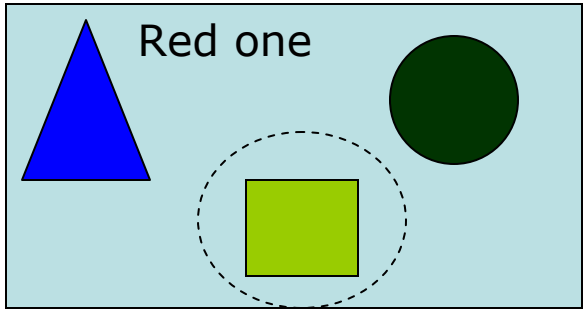
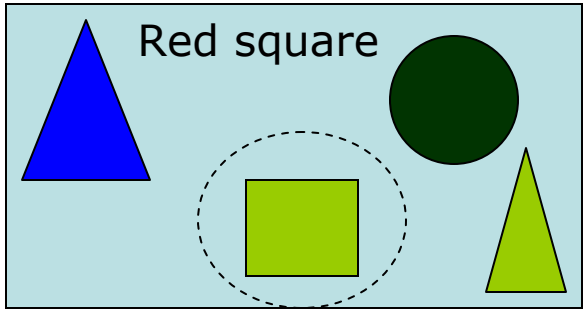
Embodied Machines

- The Talking Heads Guessing Game
  - Speakers role:
    - Speaker agent randomly searches environment, locates an area of interest (context)
    - Focuses hearer's attention on same context
    - Chooses an object in context (topic)
    - Describes object to hearer





Embodied Machines

- The Guessing Game
  - Hearer's role:
    - Hearer tries to guess what speaker is referring to
    - Indicates guess by pointing at topic (focusing)
    - Game succeeds if hearer guesses right
    - Associations between word and category strengthened
  - If hearer guesses wrong
    - Speaker points to topic as well
    - Speaker and hearer adjust strength of association between lexical item and category

Embodied Machines

- Why Guessing Game can fail:
  - Speaker has no word for object of interest
  - Hearer does not have word
  - Hearer has word but has assigned it to some other concept
  - Speaker and Hearer have different vantage points

Embodied Machines

- If speaker has no word for object of interest.
  - Speaker creates word
  - Speaker and hearer strengthen association between new word and target

Embodied Machines

- If hearer doesn't have word,
  - Speaker points to target
  - Hearer creates association between new word and target
  - Speaker reduces strength of association between word and target

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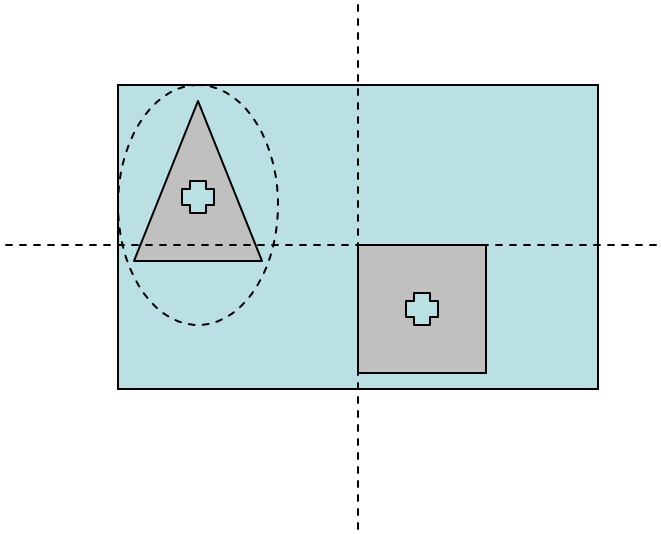
- If hearer has word, but it refers to a different concept
  - Hearer points to (wrong) target
  - Game fails
  - Speaker points to correct target
  - Hearer creates association between word and new target

Embodied Machines

- Carving up reality
  - No *a priori* categories are given to agents
  - Agents can perceive edges→contours→shapes, color, luminance, location of centers



Possible categorization strategies:

High thing
Left thing

Embodied Machines

- Correlates in biological Cognition
  - Cotton, thistle, flax
    - Human: clothing source (cotton,flax)/ weed (thistle)
    - Boll Weevil: food (cotton)/weeds (thistle & flax)
  - Absolute vs. relative reckoning systems
  - Young woman/old woman

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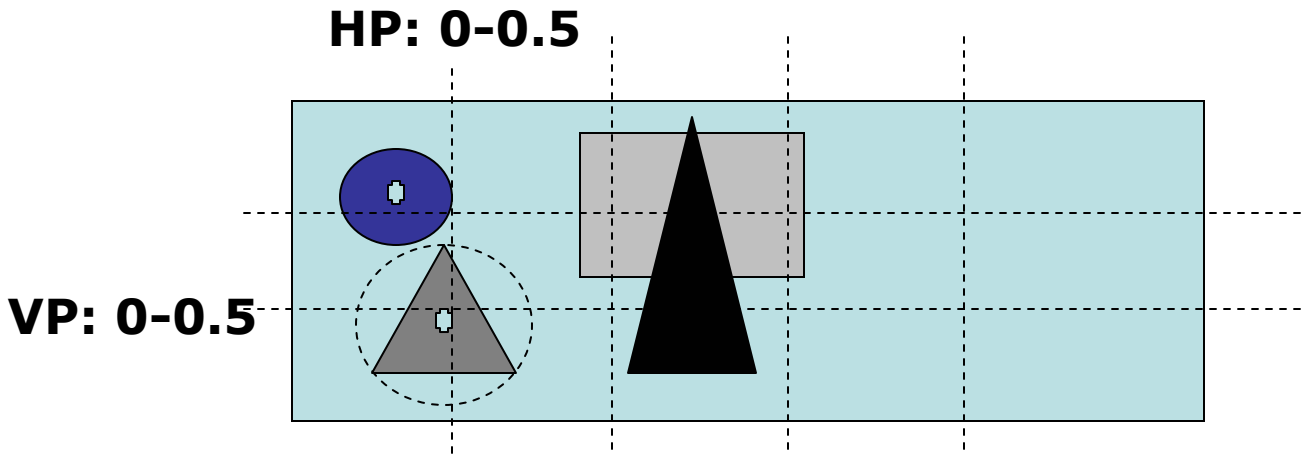
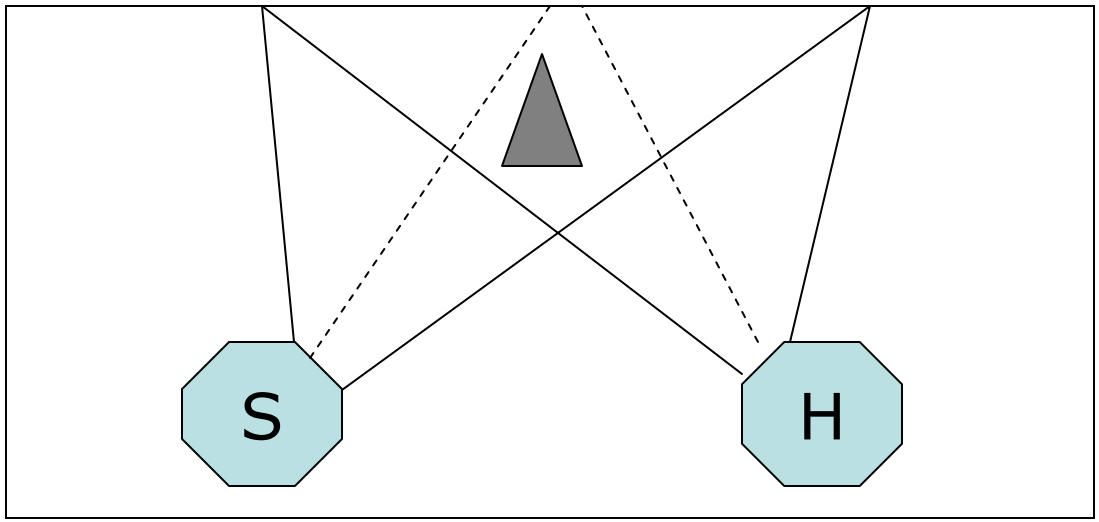
Speaker: categorizes topic as VPOS 0-0.5
says ‘lu’
Hearer: categorizes ‘lu’ as HPOS 0-0.5
says ‘lu?’ (which *lu* are you talking about?)
Speaker: points to target
Hearer: categorizes topic as VPOS 0-0.5



Embodied Machines

- Speaker and hearer have different vantage points
  - Assume agents both have Left/Right distinction
  - Left and Right have body based vantage point



Embodied Machines

- Correlates with metaphorical vantage points
  - Sandwich in a garbage can
    - Food or garbage?
    - Depends on life circumstances, personal tolerances, etc.
  - 16 year old murderer
    - Child or adult?
    - Depends on purposes of categorizer

Embodied Machines

- Ambuiguity in the system

  - Arises when agent has already associated a category with a word
  - Speaker introduces new word for same category
  - Negotiation takes place
  - Across population, forms become strengthened or pruned
  - Ambiguity can be maintained

Embodied Machines

- Achievements of Talking Heads Experiment

  - Simple robots with their own motives and perceptual systems created categories to discriminate and name objects in their environment

  - Interaction between robots produced simple languages -- shared form-meaning mappings
    - Common script --> shared goal
    - Negotiation --> Game failure led to readjustment of association strengths for both speaker and hearer

Embodied Machines

- Can embodied agents demonstrate the evolutionary advantage of a shared communication system?
  - The Emergence of a ‘Language’ in an Evolving Population of Neural Networks (Angelo Cangelosi & Domenico Parisi, (1998) *Connection Science* 10:2
  - http://www3.isrl.uiuc.edu/~junwang4/langev/localcopy/pdf/cangelosi98theEmergence.pdf

Embodied Machines

- Evolution
  - Change in the shared properties of a species over generations
  - Within a species there is always some slight, random variation in the traits inherited by individuals.
  - Variations most conducive to reproductive success will tend to become more common with each generation.
  - Evolution is the accumulation of variations that are 'selected' by nature in this way and eventually become widespread in the population.

Embodied Machines

- Properties of a language
  - System of signal-meaning correspondences with the following properties:
    - Distinct categories labeled with distinct signals
    - Single signal tends to be used to label all the instances within a category
    - All the individuals in a population tend to use the same signal to label the same category

Embodied Machines

- Human Language
  - Each individual in a population acquires language through a process of development.
  - Presupposes that there is a language—system of conventional form-meaning associations—already in place.
  - Signal-meaning correspondences are not fixed. There is syntactic structure.

Embodied Machines

- Simpler language could develop if it provides benefit to user
  - Calling/locating sexual partner (*Webb)*
  - Signals with an informative function may increases survival chances for listener
    - Less clear benefit to signal producer.

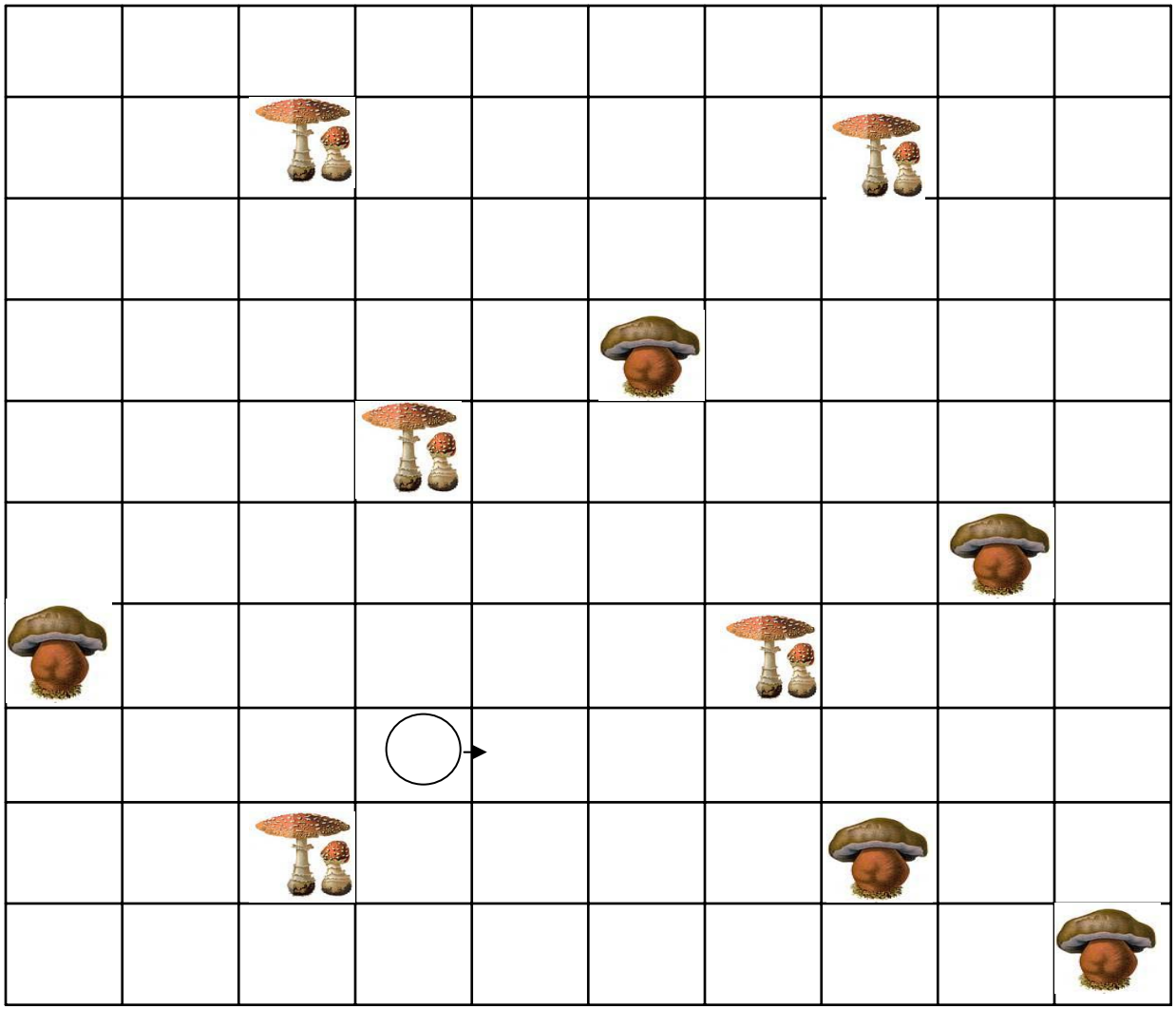
Embodied Machines

- Experimental Premises
  - Population of virtual organisms each inhabit an environment containing equal numbers of edible and poisonous mushrooms.
  - Consuming an edible mushroom increases energy (fitness), a poisonous mushroom decreases fitness.
  - The most fit organisms after specified life span produce offspring – organisms that inherit the genetic code (weights) of the parent plus a 10% mutation.

Embodied Machines

- Importance of Mutation
  - The occurrence of mutation in the population of a species ensures that there is always a fresh supply of variation available—the 'fuel' of natural selection.
  - If mutant genes were to cease to occur, evolution would eventually come to a halt, resulting in a species made-up of more or less identical individuals, unable to adapt to changes in its environment.

Environment



 = poisonous

 = Edible

Embodied Machines

- The effect of Language on Fitness
  - Mushrooms have perceptual properties detectable only when organism is immediately adjacent to mushroom.
  - A signal from a conspecific closer to a mushroom could help organism identify and approach food, making foraging more efficient and thereby increasing his reproductive chances

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- Since greater fitness corresponds to increased reproductive success, the ability to categorize mushrooms should evolve.
- Could language emerge when only receiver is directly benefited by language.
- Pressure for whole population to evolve same language.

Embodied Machines

- Experimental Set-up
  - Organism inhabits 20x20 cell environment 10 edible and 10 poisonous mushrooms
  - Organism/mushrooms randomly placed in environment
  - Every organism lives 750 time units

    equal to 15 epochs of 50 learning cycles of neural network
  - After each epoch, environment repopulated with mushrooms

Embodied Machines

- Neural Networks in a nutshell
  - A neural network is a *function,* a means of mapping from inputs to output
  - A neural network is a classifier: it takes features as inputs (encoded numerically) and outputs categories (also encoded numerically)
  - Original output is random. Adjustments to function occur through *training*. Adjustments reduce error between output and actual values
  - Neural Networks are modeled after biological systems--have some properties of biological cognition

Embodied Machines

- Inputs to this neural network
  - Object Location: *Angular distance from direction faced to closest mushroom (decimal number 0-1)*
  - Perceptual Properties (20 types):

    edible 1111100000 + *one change*

    poisonous 0000011111 + *one change*
  - Language Signals: *3 bit encoding (8 possible)*
    - *000,001,010…*
- Outputs from neural network
  - Movement code

    11 = *forward,* 01 = *right*, 10 = *left,* 00 = *stay*
  - Language Signal (encoded as above)

Embodied Machines

- Three populations of 100 organisms compared over 1000 generations:
  - No Language
  - External Language
  - Evolving Language

Embodied Machines

- Group 1: No language
  - Output signals emitted, never received.
- Group 2: External Language
  - Organism not adjacent to mushroom is fed input from external 'teacher'
  - External input is from established language
- Group 3: Evolving Language
  - Organism not adjacent to mushroom is fed input from a random naïve conspecific
  - At outset, neither organism has learned to categorize mushrooms
  - There is no *a priori* signaling system.

Results

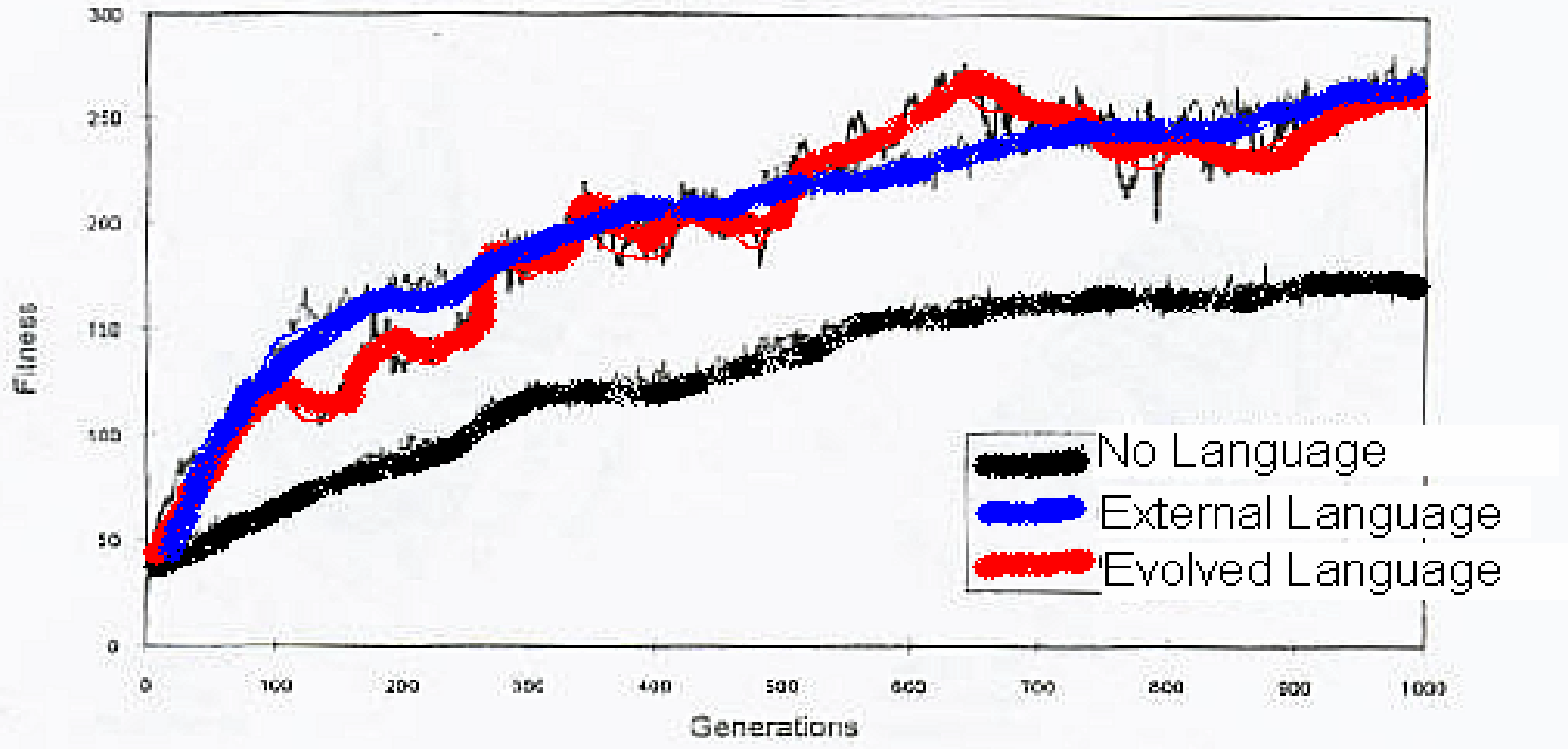

Figure 2. Average fitness across 1000 generations of three different populations: without language, with externally imposed language and with evolved language. Each curve is the average of five different replications of the same simulation.

Embodied Machines

- Non-language users are less fit after 1000 generations.

- Both groups of language users are equally fit after about 400 generations.
  - Externally provided language provides steeper climb in beginning

Embodied Machines

- Summary of results
  - Emergence of a simple language through evolutionary processes possible when there is an associated reproductive advantage.
  - There is an apparent strong interdependence between the evolution of language and the evolution of cognition