Division of Labor

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Division of Labor In Social Insects

- Different tasks within a colony of insects are performed simultaneously by specialized individuals
- Specialization is more efficient

- Example: Reproductive Division of Labor:
- Reproductive caste: Contains fertile females and males
- Worker caste: Sterile females that care for the reproductive caste

Worker Division of Labor

- Temporal Polyethism: Workers of a similar age tend to perform similar tasks
- Worker Polymorphism: Workers can belong to different morphological castes, e.g., Soldier or Major castes
- Individual Variability: Even amongst the other castes there can be differences in frequency and sequences of various tasks

Division of Labor Rigidity

- Division of Labor is rarely fixed for workers
- Worker force must be allocated to different tasks to adjust to new conditions
- Different castes of workers can be made to perform the tasks of other castes based on stimuli

Response Thresholds

- Individuals perform a task when the stimuli for that task exceed the individual's threshold
- If individuals responsible for a task are unable to complete it, the stimuli for that task increases
- Feeding larvae and corpse removal are two examples

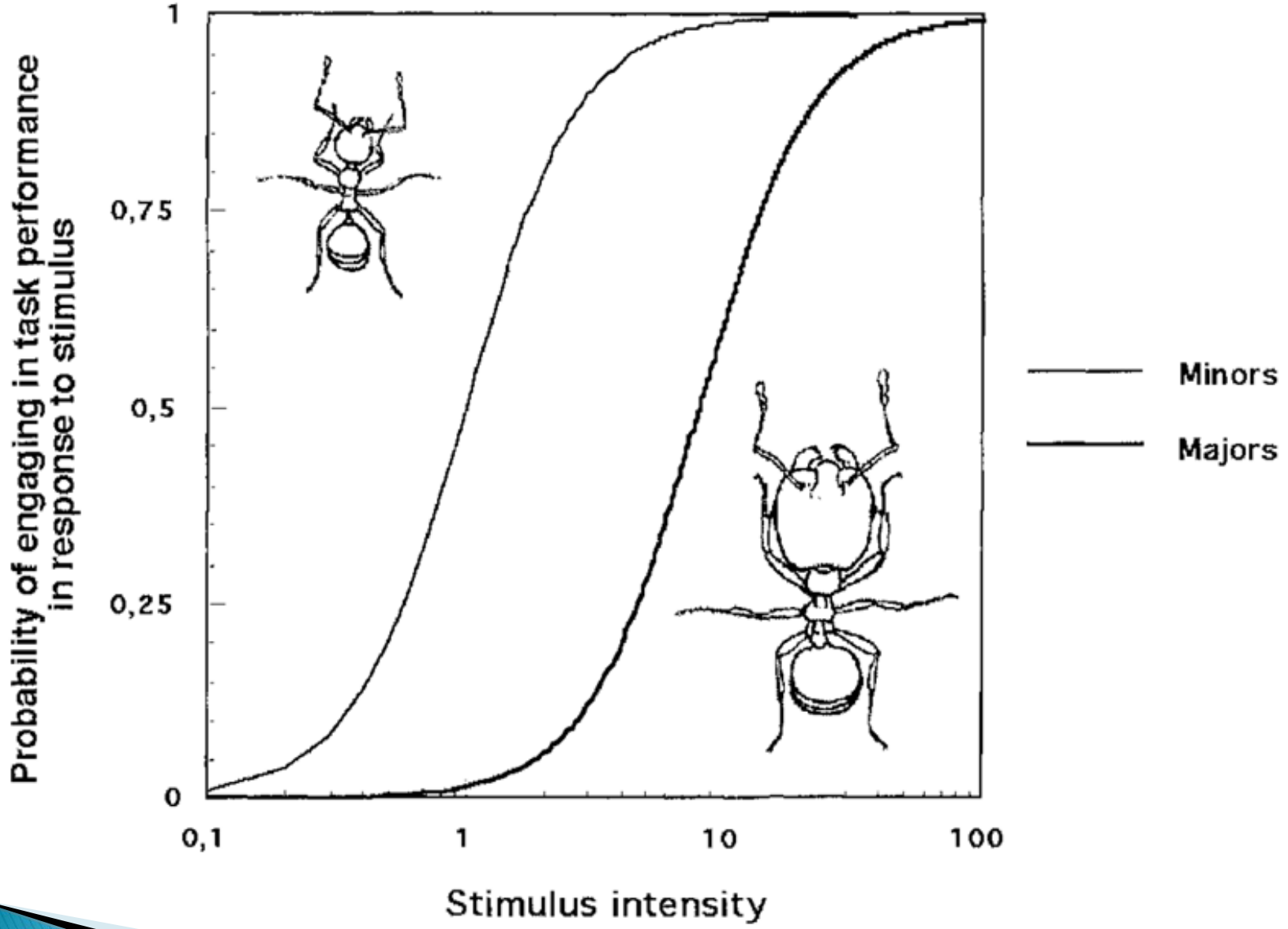
Model for Response

$$T_\theta(s) = \frac{s^n}{s^n + \theta^n}$$

- Where:
  s = intensity of the stimulus
  Θ = Response Threshold
  n = steepness of threshold (use n = 2)

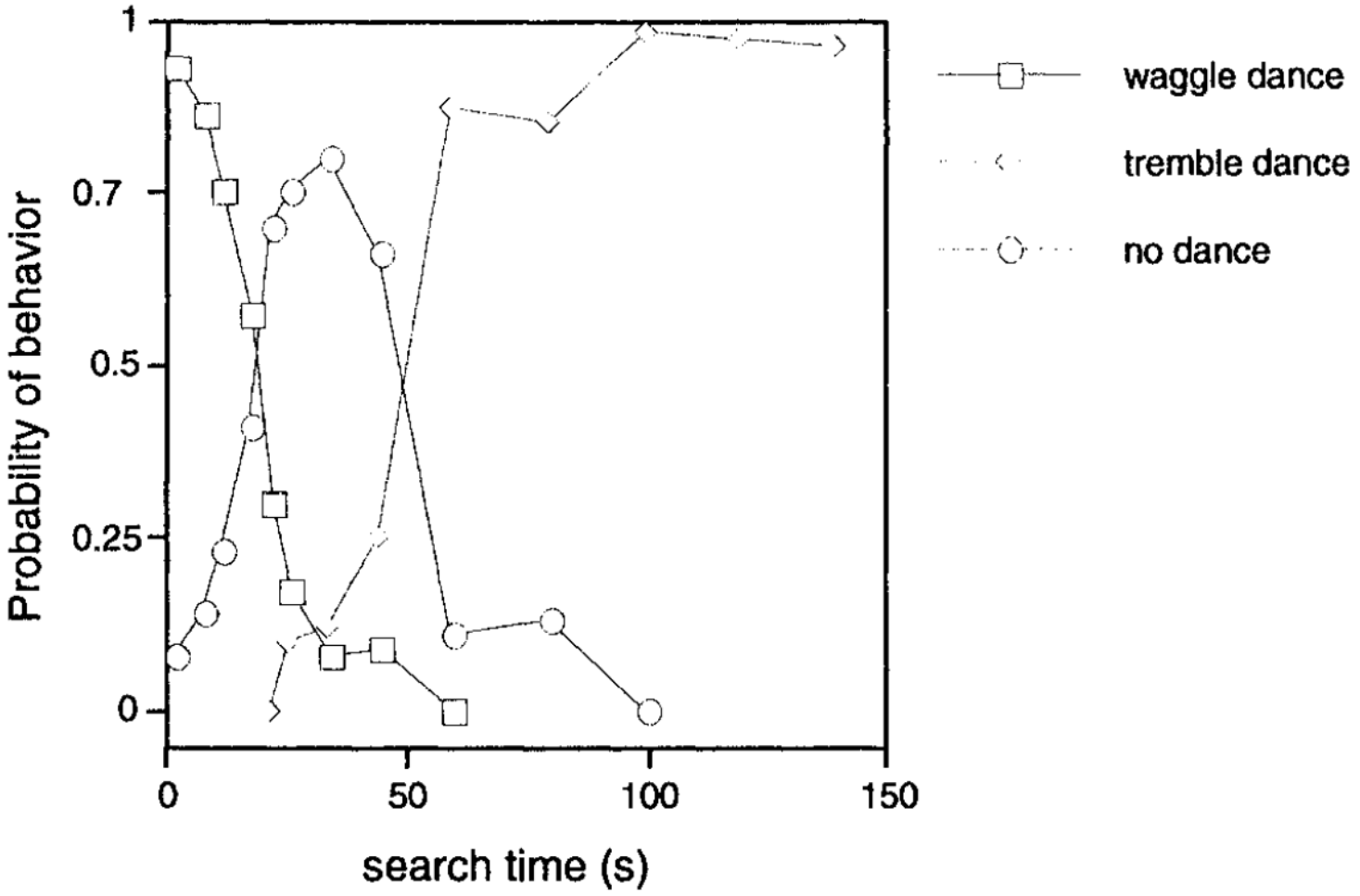
- Alternate Exponential Model:

$$T_\theta(s) = 1 - e^{-s/\theta}$$


Probability of engaging in task performance in response to stimulus
1
0,75
0,5
0,25
0
0,1
1
10
100
Stimulus intensity
Minors
Majors

Example: Honey Bees

- If forager bees take too long to unload nectar the bee does a “tremble” dance to recruit more storer bees
- If the bee unloads quickly, then it does a “waggle” dance and recruits more forager bees
- If it takes a certain amount of time, then the bee simply returns to the food source with no dance


Probability of behavior
1
0.7
0.5
0.25
0
0
50
100
150
search time (s)
waggle dance
tremble dance
no dance

Abandoning A Task

- Individuals can abandon a task with probability p
- Average time spent on a task : 1/p
- If the stimulus for a task is high, the individual may resume the task shortly after abandoning it

Stimulus Modeling

$$s(t+1) = s(t) + \delta - \frac{\alpha N_{\text{act}}}{N}$$

- Where:

  N_{act} = number of active individuals

  N = total number of potentially active individuals

  δ = increase in stimulus intensity

  α = scale factor for efficiency

Further Analysis

- Worker activity can be modeled with:

$$\partial_t x_1 = T_{\theta_1}(s)(1 - x_1) - p x_1$$

- Where:

  x = proportion of active workers of that type (N_{act} / N)

Even Further Analysis

$$x_1^s = \frac{\chi + (\chi^2 + 4f(p+1)(z-1)(\delta/\alpha))^{1/2}}{2f(p+1)(z-1)},$$

where

$$\chi = (z-1)\left(f + (p+1)\frac{\delta}{\alpha}\right) - z.$$

z = ratio of that type's threshold over other thresholds

f = fraction of that type of insect

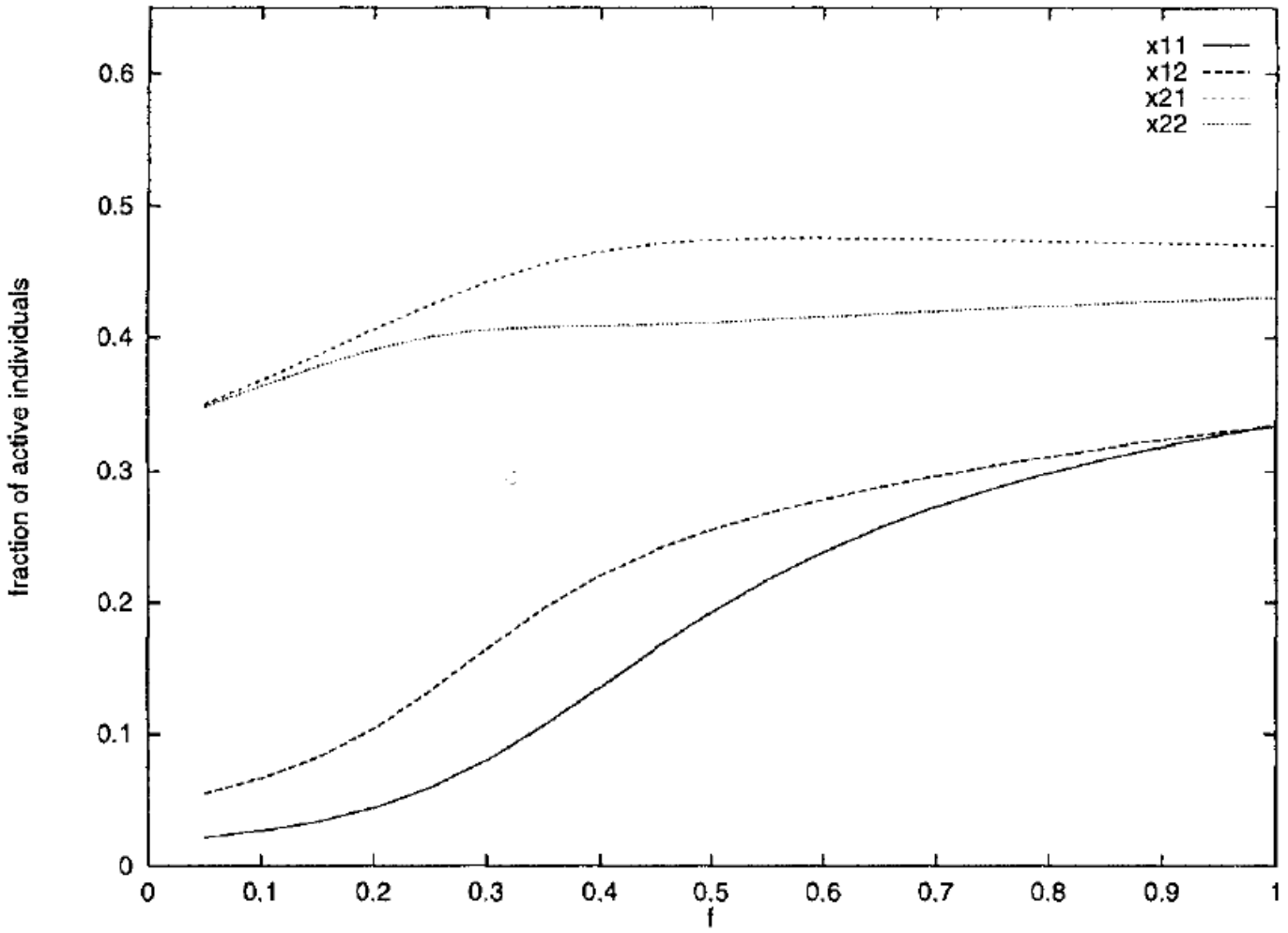
Modeling With Multiple Tasks

$$\partial_t x_{ij} = \frac{s_j^2}{s_j^2 + \theta_{ij}^2} \left(1 - \sum_{k=1}^{m} x_{ik} \right) - p x_{ij}$$

- Where:
- M = number of tasks going on at the time

$$\partial_t s_j = \delta - \alpha f x_{1j} - \alpha (1 - f) x_{2j}$$

J corresponds to different tasks



$\Theta_{11} = 8, \Theta_{12} = 5, \Theta_{21} = 1, \Theta_{22} = 1$

Questions?