Quorum sensing without counting, a discounting approach

…or…

"Nobody goes there anymore, it's too crowded"

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Arizona State University
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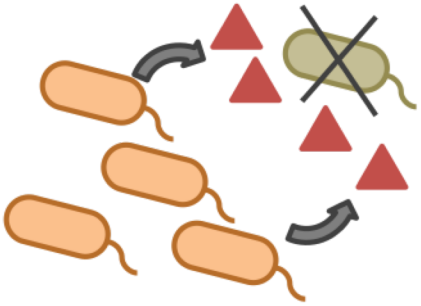
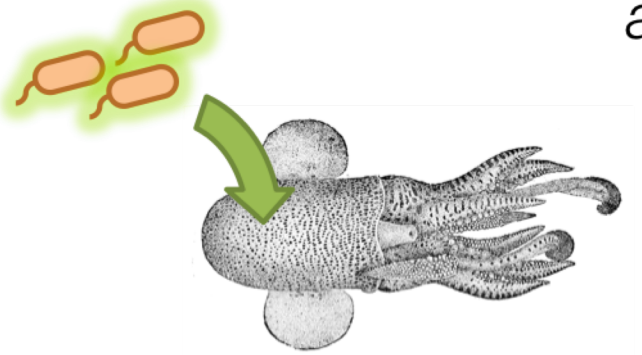
Collaborators: Jake Hanson, Dr. Gabriele Valentini, Dr. Sara Imari Walker, Dr. Stephen C. Pratt

Bacterial Quorum Sensing

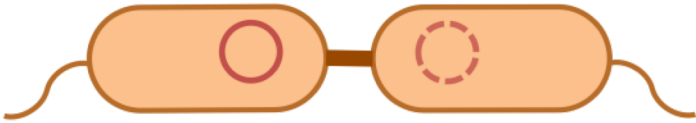


antibiotic production

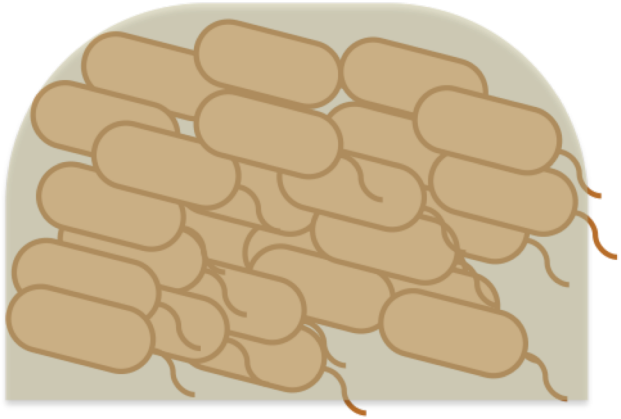


bioluminescence

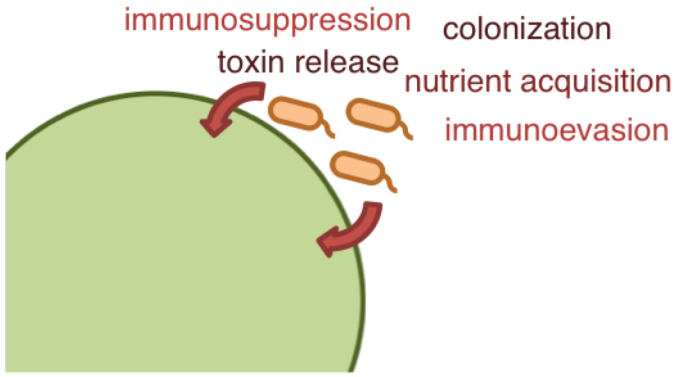
collective behaviors



conjugation



biofilm formation

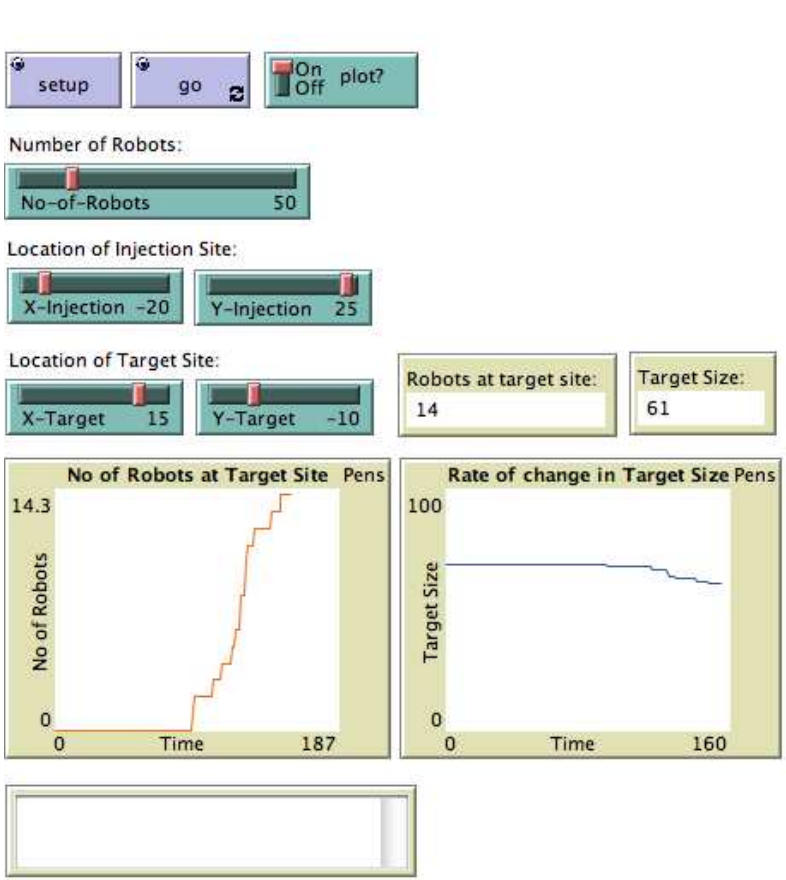


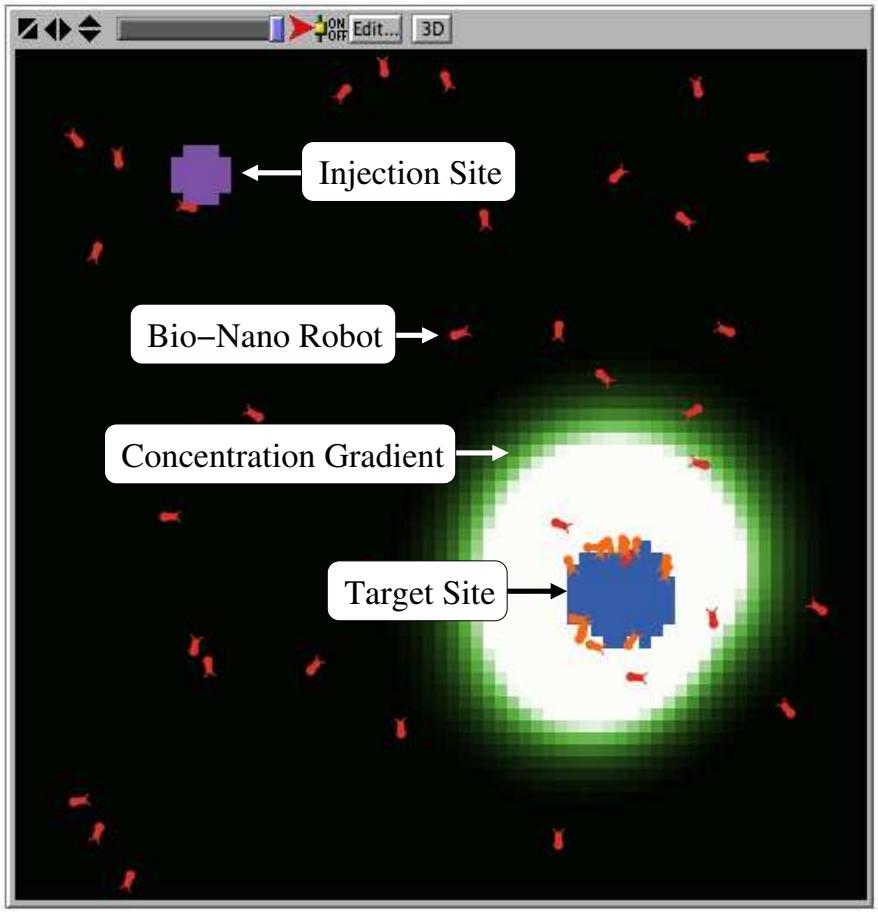
virulence factors

(via Matthew Ryan and Laura Washburn)

Swarm Intelligence for Cooperation of Bio-Nano Robots using Quorum Sensing

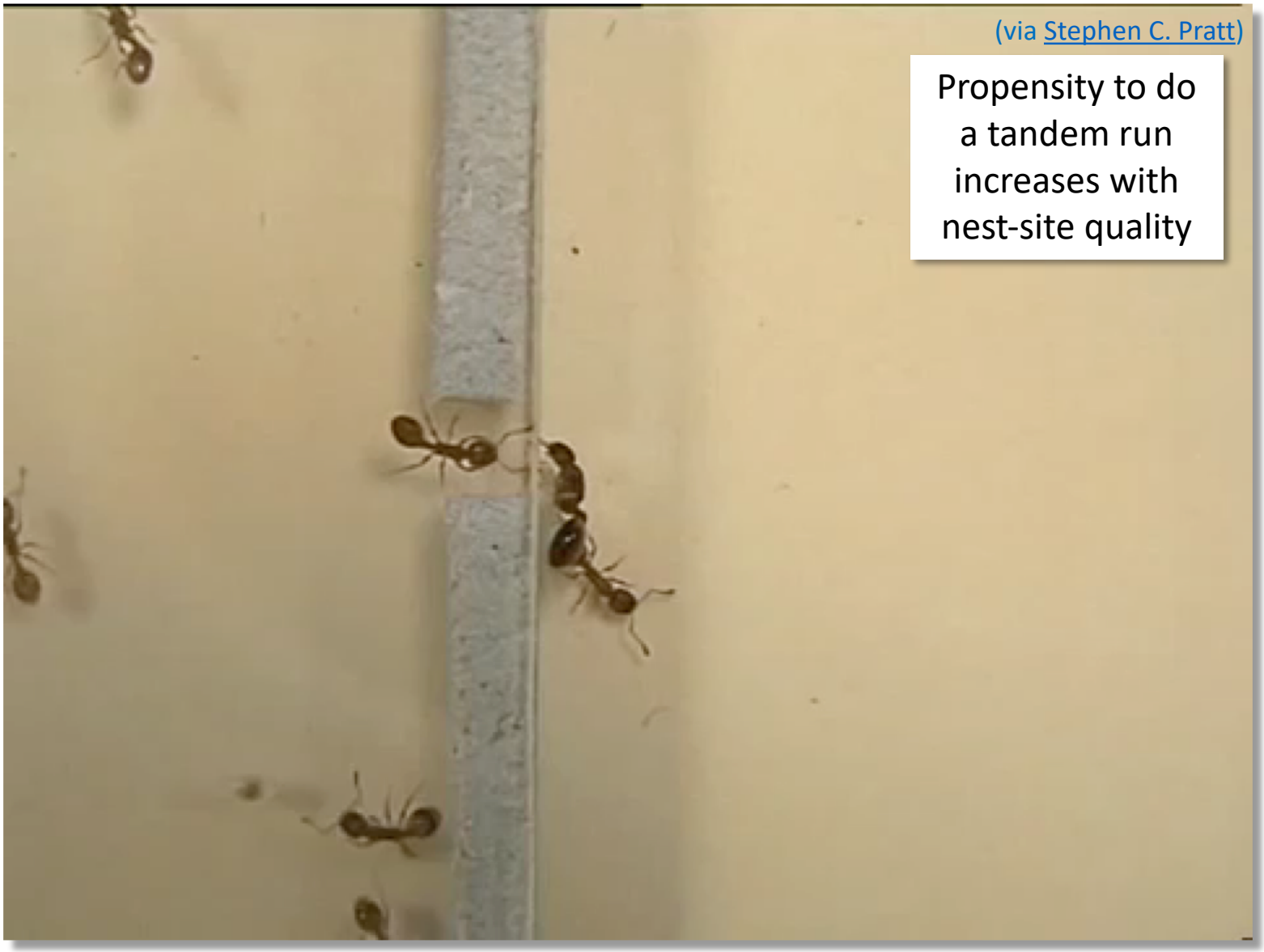
Sreedevi Chandrasekaran and Dean F. Hougen





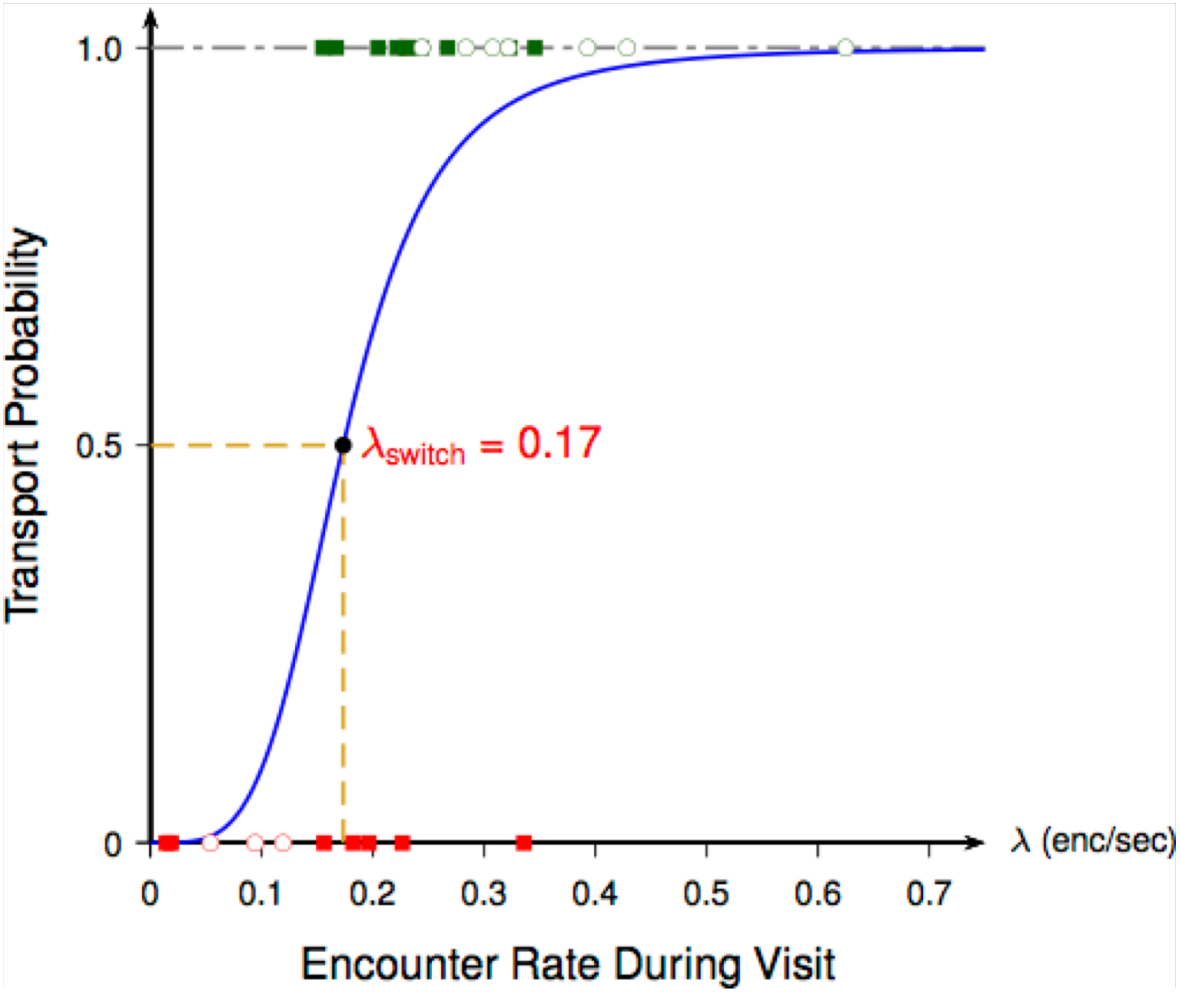
(Chandrasekaran and Hougen, 2006, *ASM-IEEE Conference on Bio-, Micro- and Nanosystems*)

Crevice-dwelling, house-hunting *Temnothorax* ants



“Tandem running” behavior

“Transport” behavior



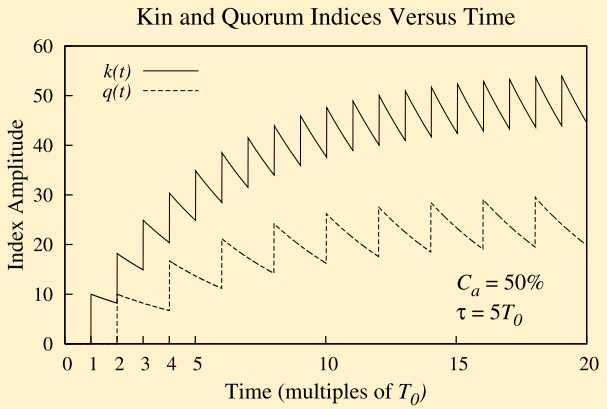
Decision Accuracy

(Pratt, 2005, *Behav. Ecol.*)

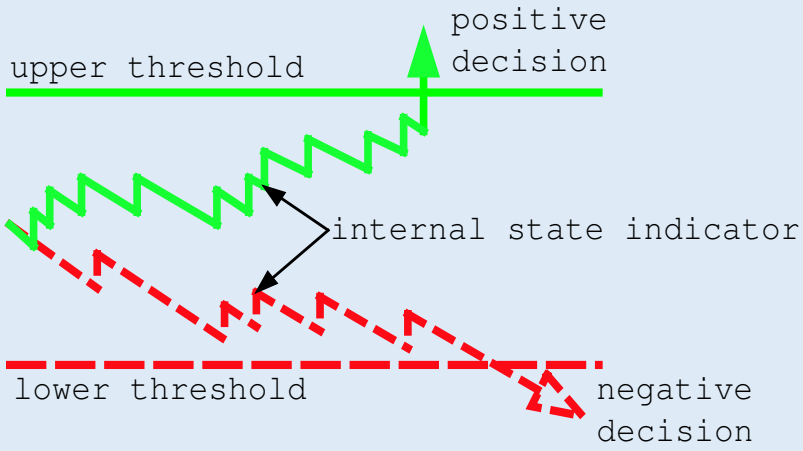
Approaches from Engineering and Computer Science

"**Counting** and Calculating"

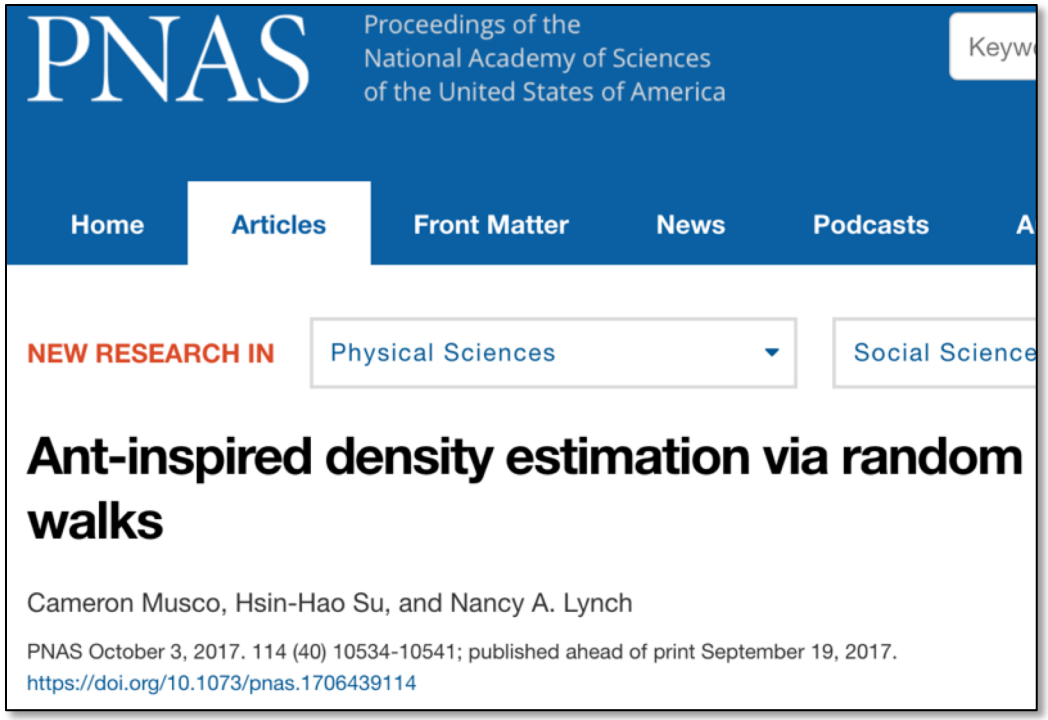
Musco, Su, and Lynch (2017, *PNAS*) **[*BDA 2016*]**
Parker and Zhang (2010, *Swarm Int.*)
Parker and Zhang (2009, *IEEE/ASME Trans. Mechatronics*)
Parker and Zhang (*IROS 2004*)

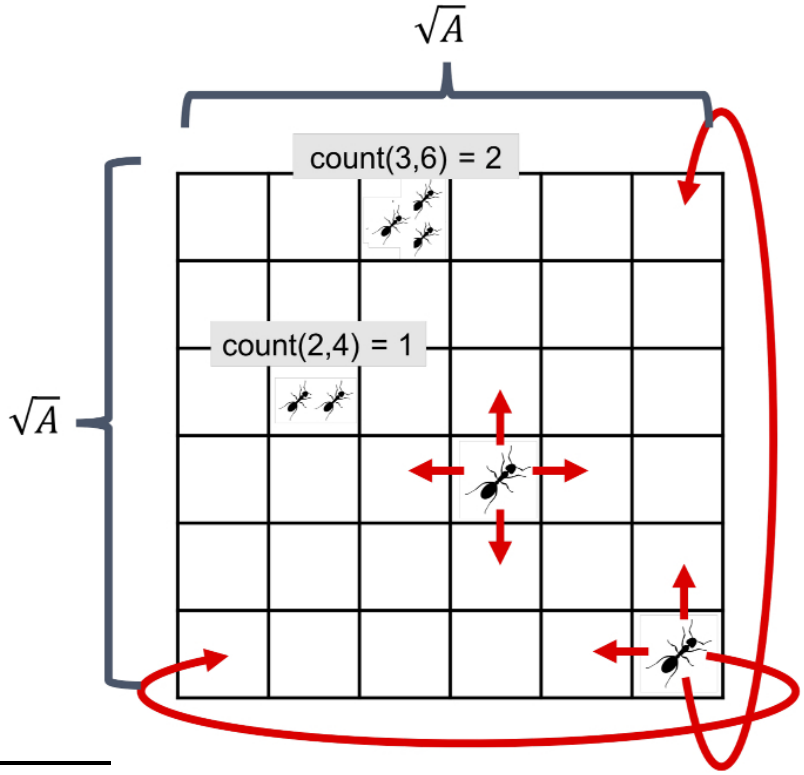


"**Counting** and Thresholding"



Peysakhov and Regli (*SIS 2005*)





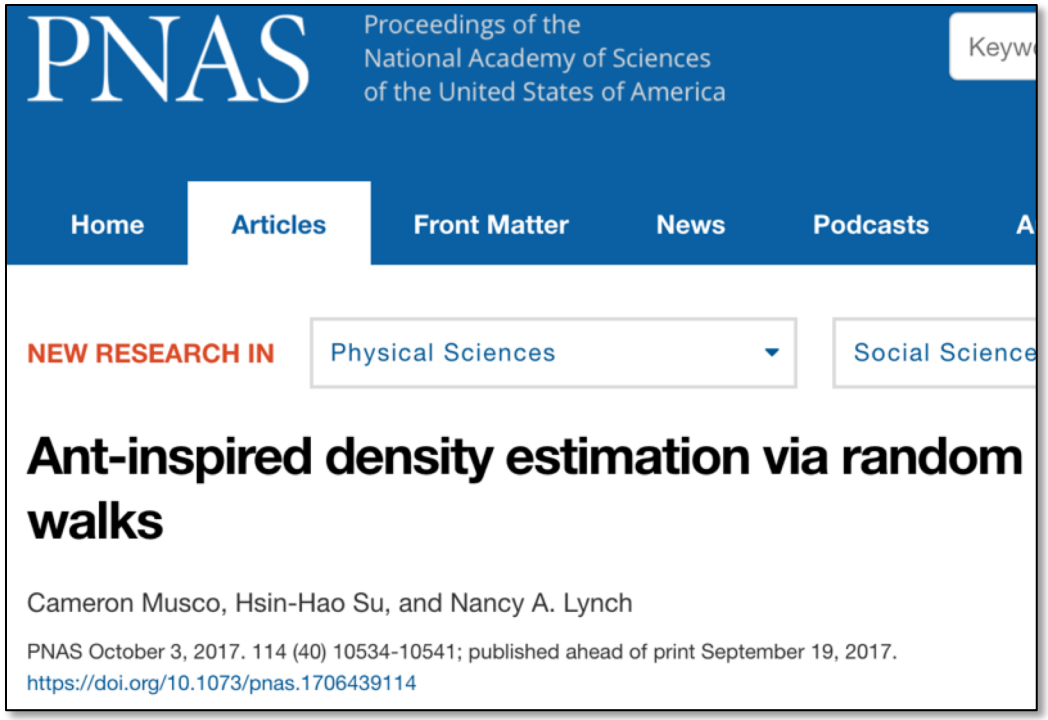
Algorithm 1 Random-Walk-Based Density Estimation

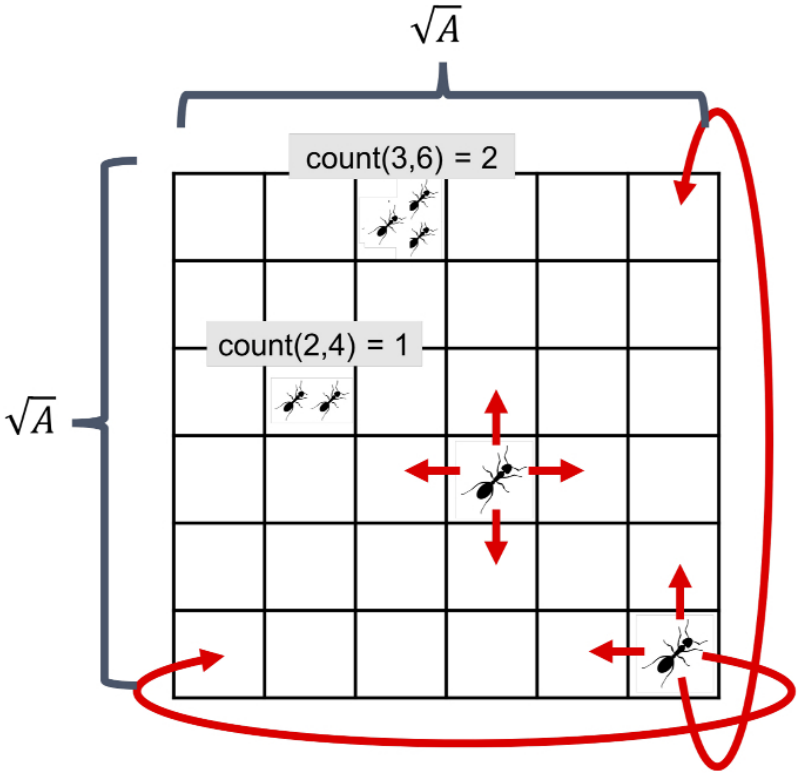
Each agent independently executes:

$c := 0$
for $r = 1, ..., t$ **do**
  $step := rand\{(0,1),(0,-1),(1,0),(-1,0)\}$
  $position := position + step$
  $c := c + count(position)$ ▷ Update collision count.
return $\tilde{d} = \frac{c}{t}$

Number of rounds *t* chosen by ant/evolution.

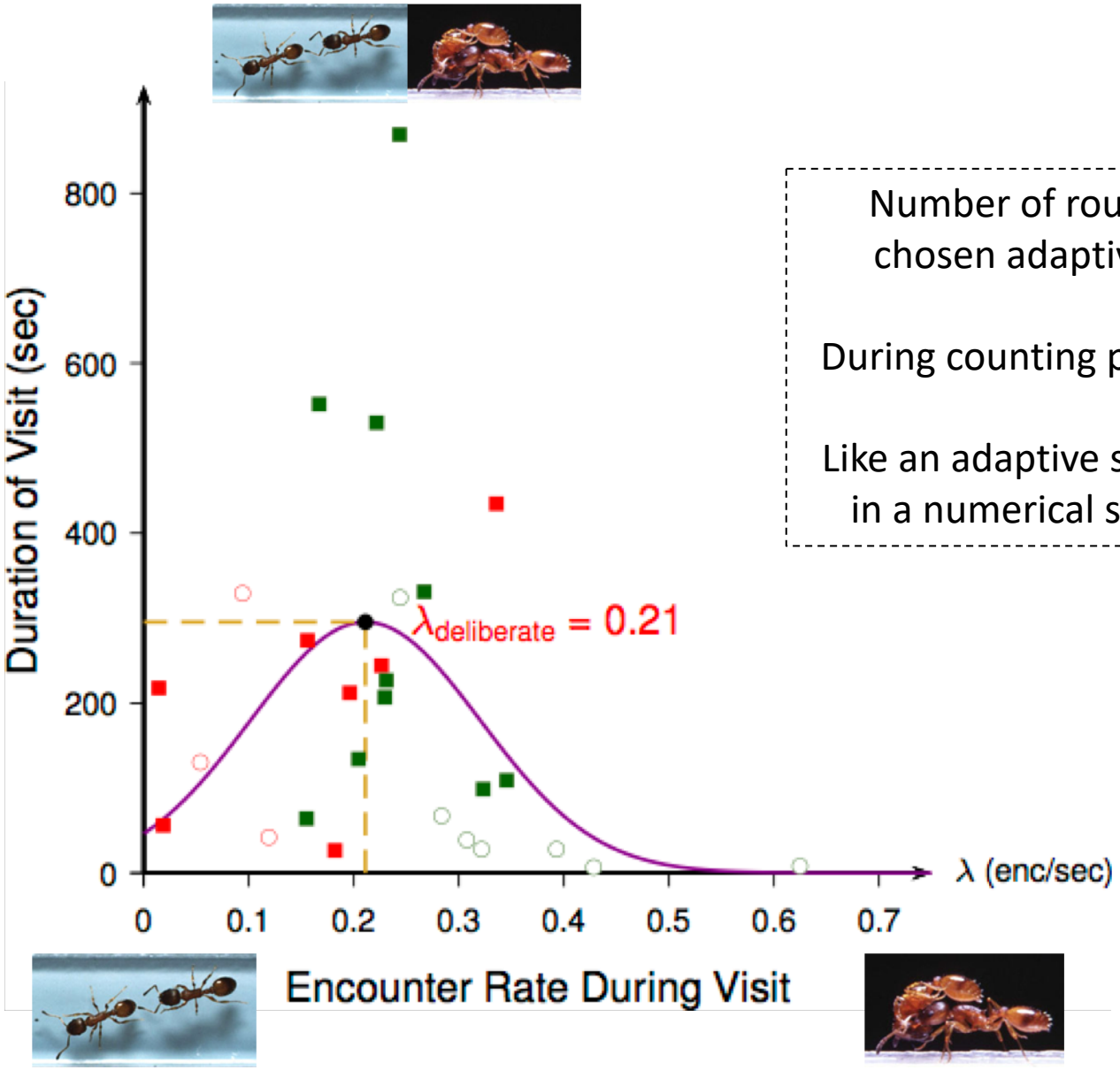
- Nearby agents collide repeatedly
- Cannot recognize duplicate collisions
- Yet **counting algorithm** will converge to actual density





Is ***counting and calculating*** the right computational model for **ant** quorum sensing?

Is there a ***simpler way*** for robotic quorum sensing and other spatial applications?



Number of rounds *t* chosen adaptively?

During counting process?

Like an adaptive step size in a numerical solver?

Decision Latency

(Pavlic and Pratt, in prep)

Psychological Review
1999, Vol. 106, No. 2, 261–300

0033-295X/99/$3.00

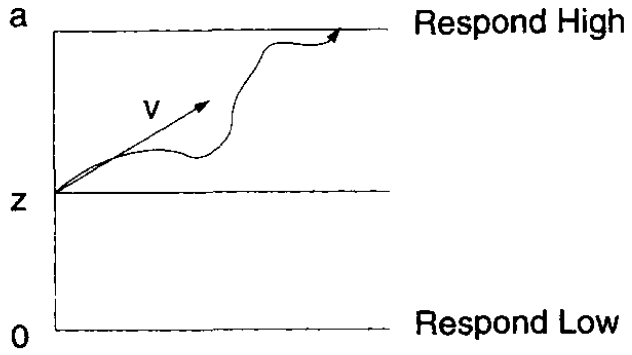
Connectionist and Diffusion Models of Reaction Time

Roger Ratcliff
Northwestern University

Trisha Van Zandt
Johns Hopkins University

Gail McKoon
Northwestern University

Two connectionist frameworks, GRAIN (J. L. McClelland, 1993) and brain-state-in-a-box (J. A. Anderson, 1991), and R. Ratcliff's (1978) diffusion model were evaluated using data from a signal detection task. Dependent variables included response probabilities, reaction times for correct and error



Parameters of the Diffusion Model:
a = Boundary position
z = starting point = a/2
v = mean drift rate, one for each condition
s = standard deviation in drift within a trial
T_{er} = encoding and response time
η = standard deviation in mean drift rate from trial to trial (drift is $N(v,\eta)$)
s_z=standard deviation in starting point (starting point is $N(z,s_z)$)

Could a ants be using the same mechanisms for quorum detection as humans?

(Pavlic and Pratt, in prep)

Psychological Review
1999, Vol. 106, No. 2, 261–300

0033-295X/99/$3.00

Connectionist and Diffusion Models of Reaction Time

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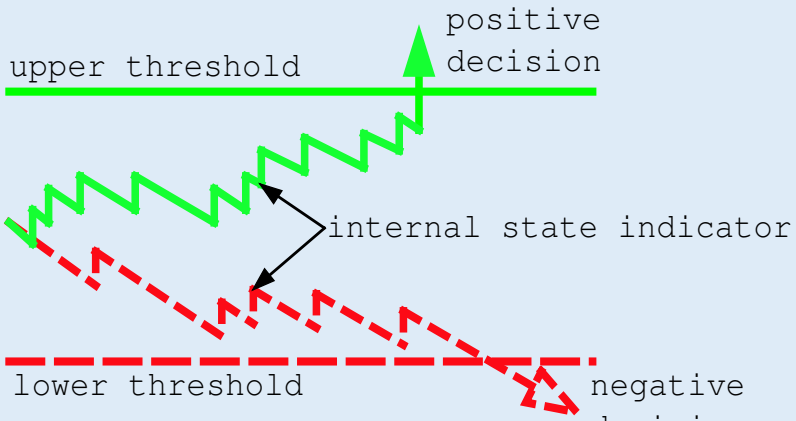
"**Counting** and Thresholding"



Peysakhov and Regli (*SIS 2005*)

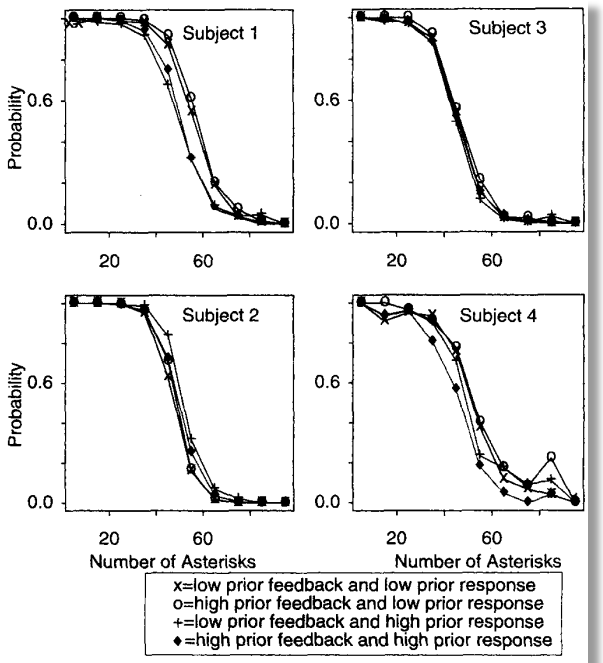


Figure 1. Probability of a low response for the four subjects in Experiment 1.

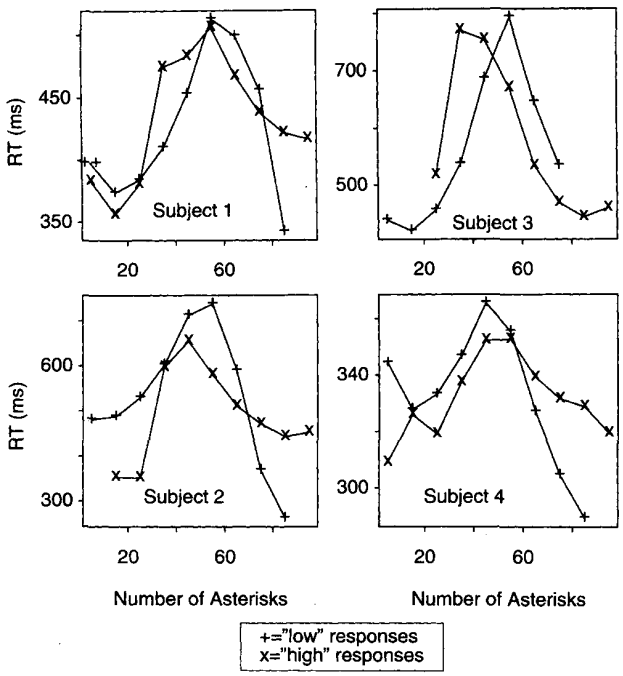
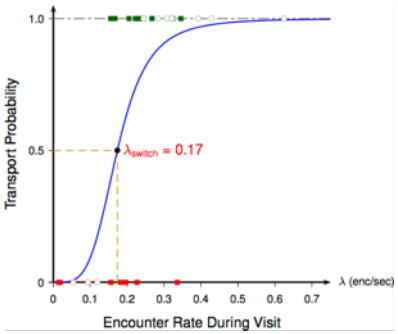
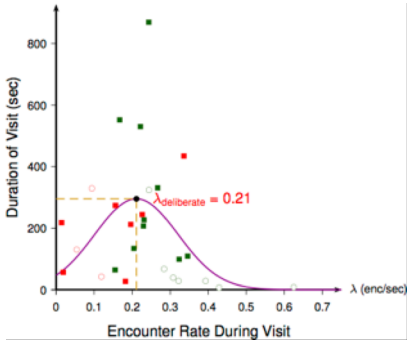


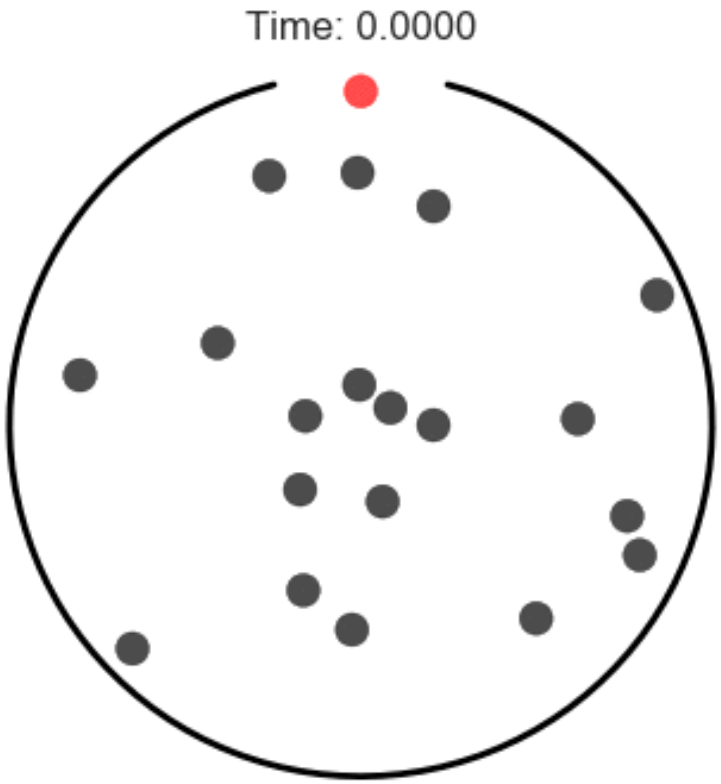
Figure 2. Mean reaction time (RT) for the four subjects in Experiment 1.



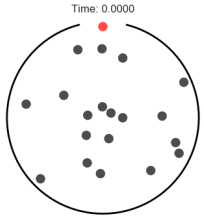


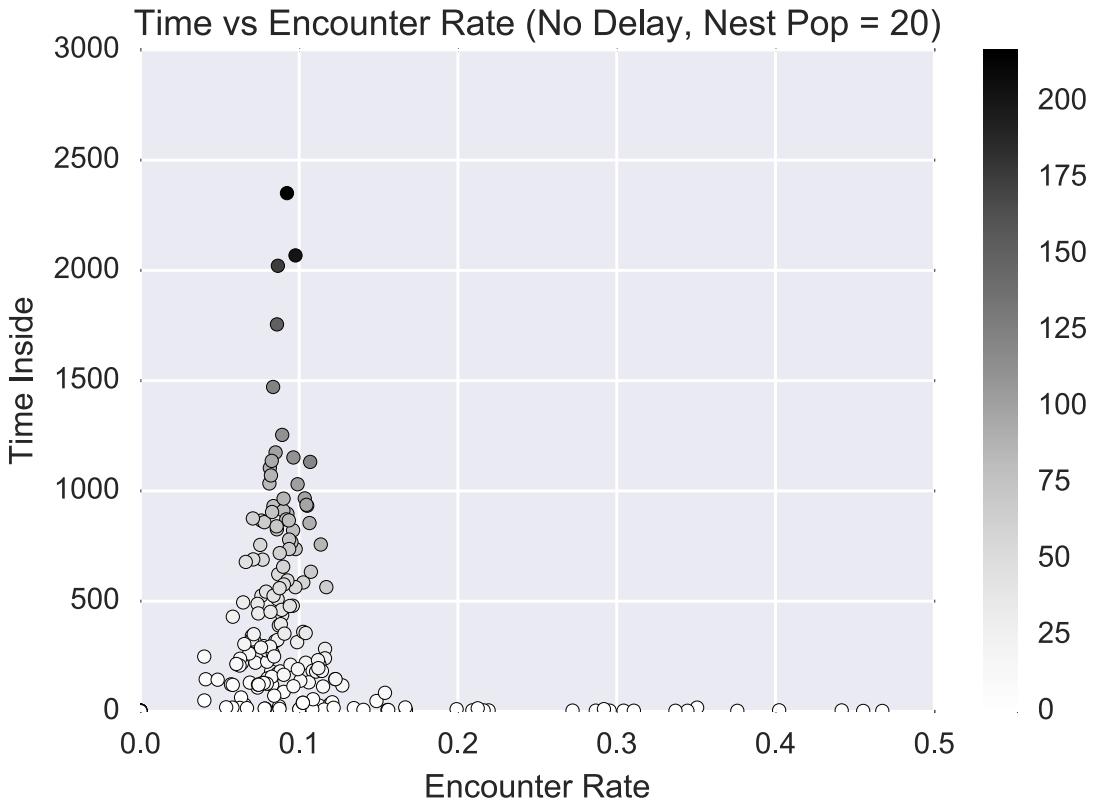
So maybe **dueling counters** and **thresholds** are involved in setting the adaptive sampling period?

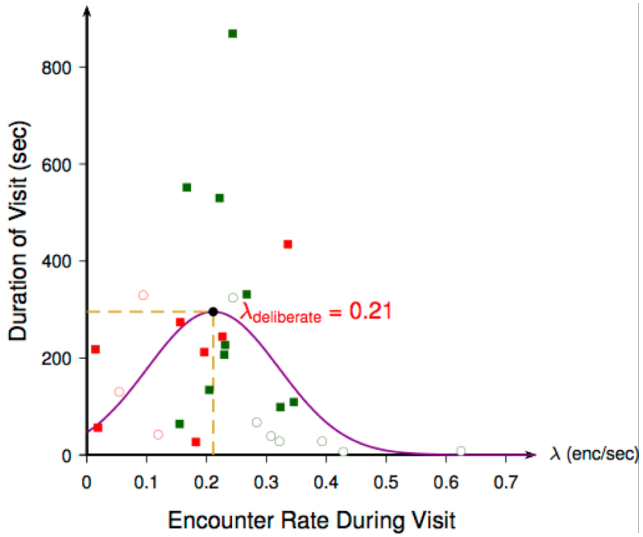
(Pavlic and Pratt, in prep)



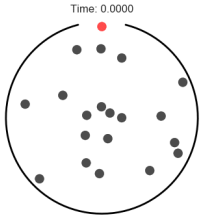
Does the process have to be **cognitive** at the level of an **individual**?



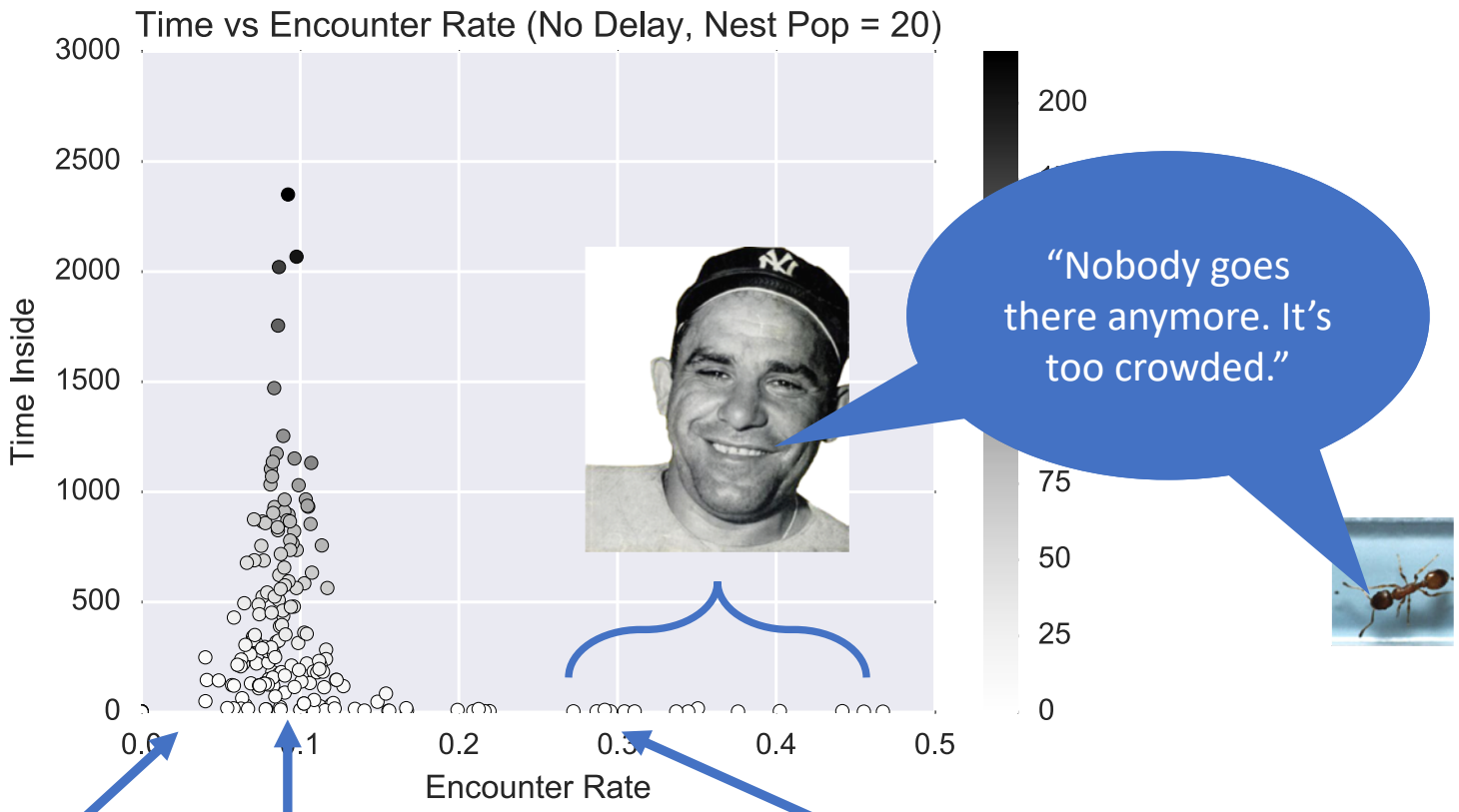




Observed decision latency is exactly what is expected from a naïve 2D random walk amongst hard spheres.



Sampling period is set by ***physical space***.

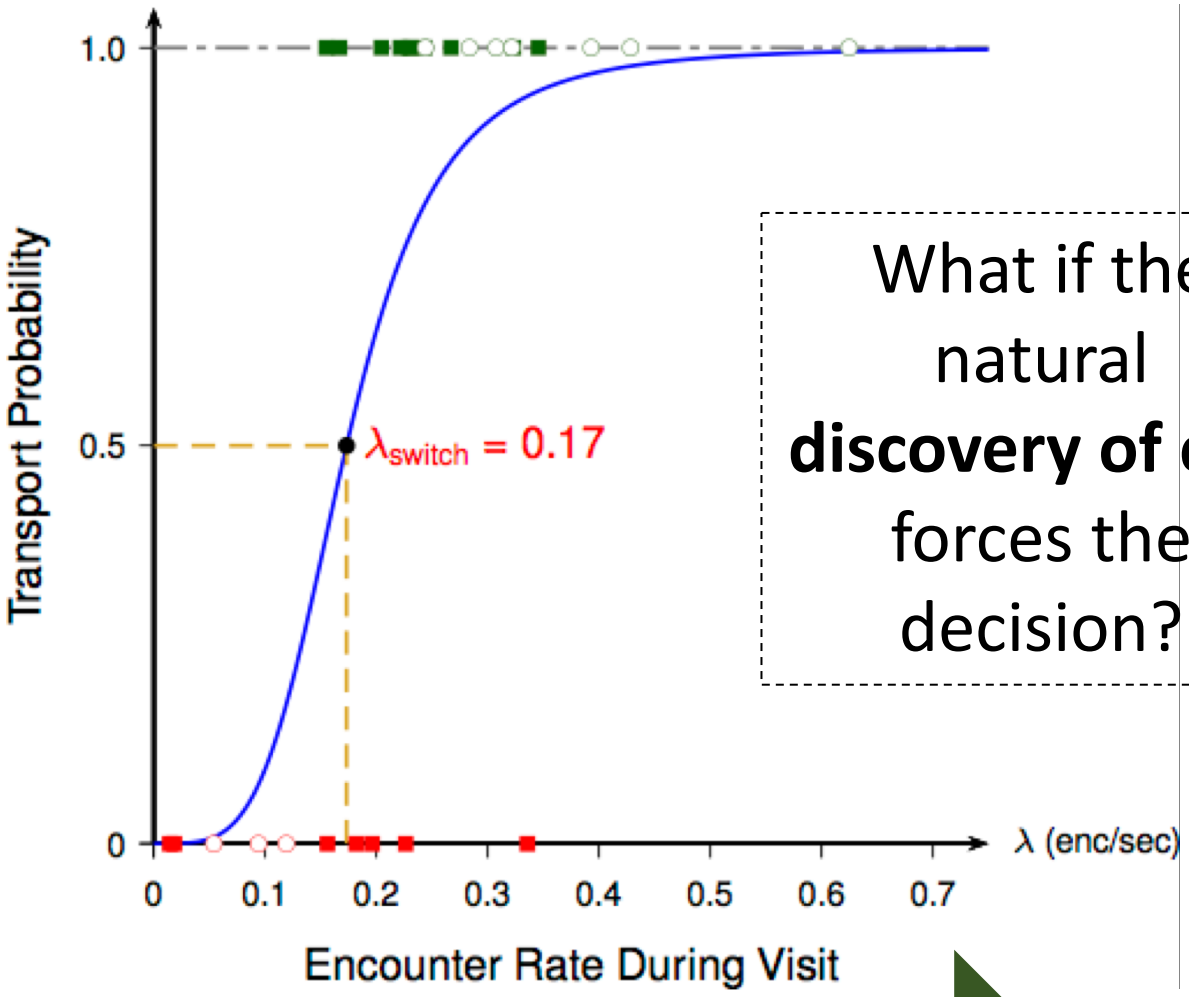


Empty Cavity
2D Brownian Recurrence Time

Intermediate Packing
Brownian Recurrence Time for >2 Fractal Dimension

Tight Packing
1D Brownian Recurrence Time
then
Low Penetration Depth

Sampling period is set by ***physical space***.



What if the natural **discovery of exit** forces the decision?

An encounter is likely ***long*** before exit

Tandem Run

An encounter is likely ***shortly*** before exit

Transport

Social foraging in honey bees: how nectar foragers assess their colony's nutritional status

Thomas D. Seeley
Section of Neurobiology and Behavior, Mudd Hall, Cornell University, Ithaca, NY 14853, USA

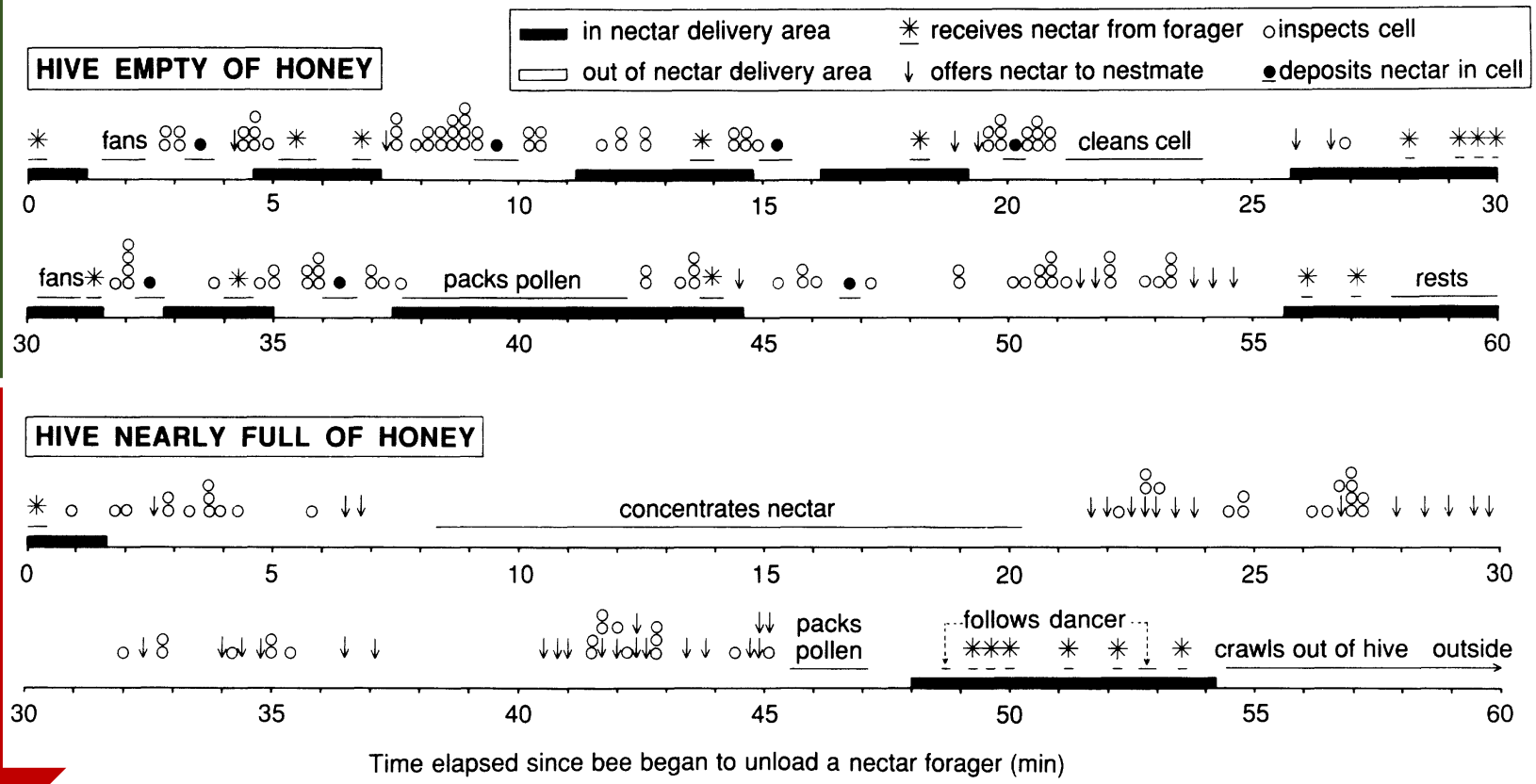
Behavioral Ecology and Sociobiology

Recruit

An encounter is likely ***shortly*** after entrance

Do not recruit

An encounter is likely ***long*** after entrance



(Seeley, 1989, *BES*)

Do not recruit

An encounter is likely ***long*** after entrance

Recruit

An encounter is likely ***shortly*** after entrance

VOL. 82, NO. 4 JULY 1975

Psychological Bulletin

Specious Reward: A Behavioral Theory of Impulsiveness and Impulse Control

George Ainslie
Massachusetts Mental Health Center, Boston

Temporal discounting

The perceived value of a reward/stimulus decreases with time since the event

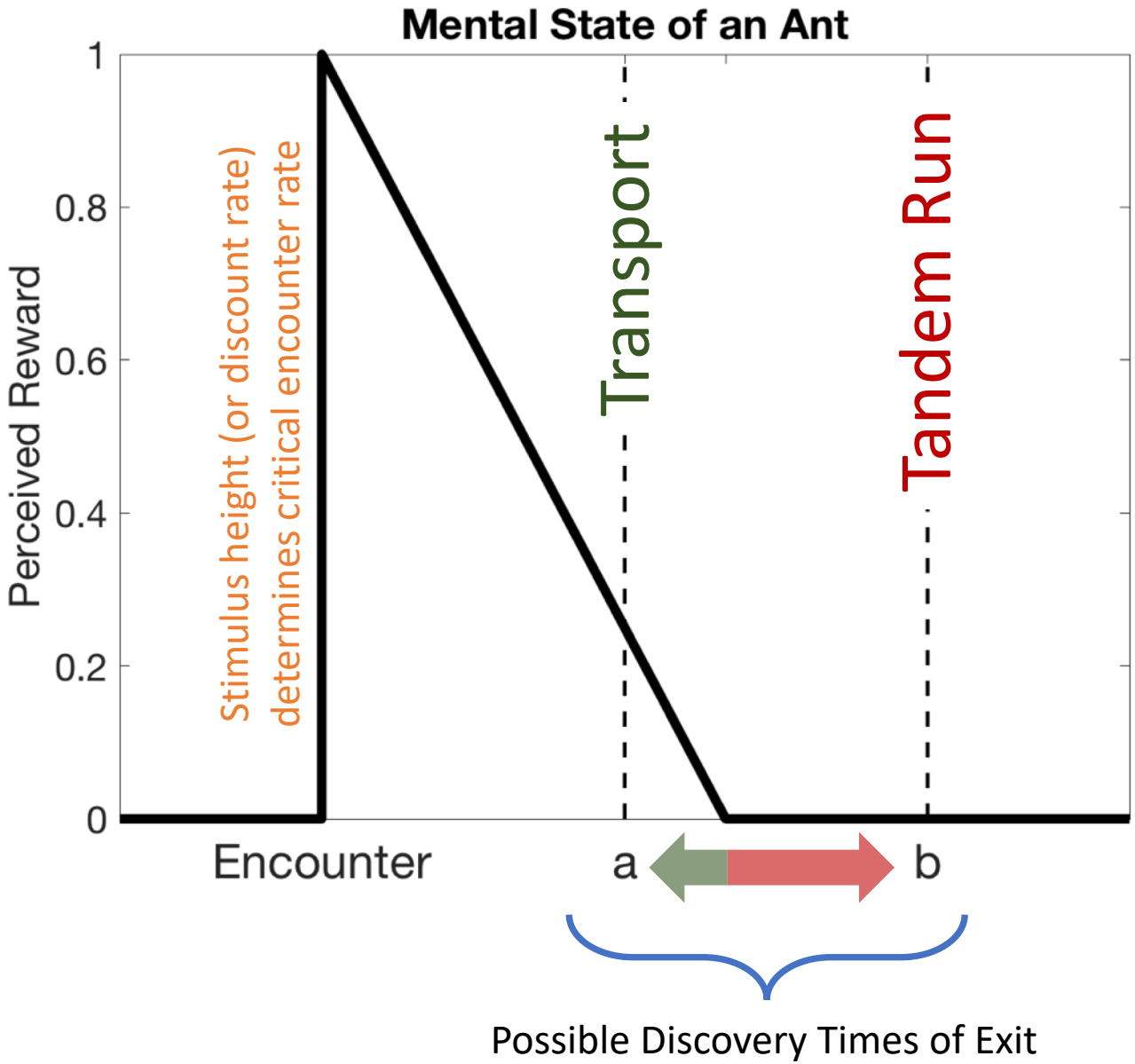
An encounter is likely ***long*** before exit

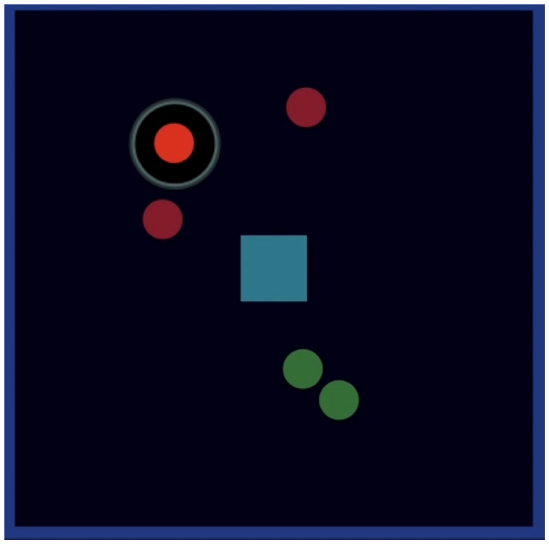
Tandem Run

An encounter is likely ***shortly*** before exit

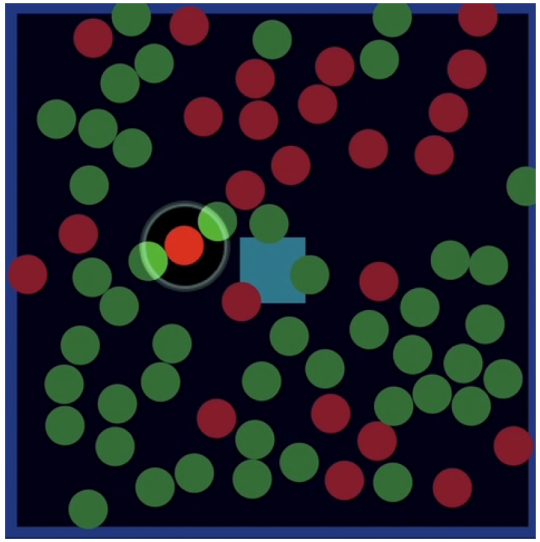
Transport

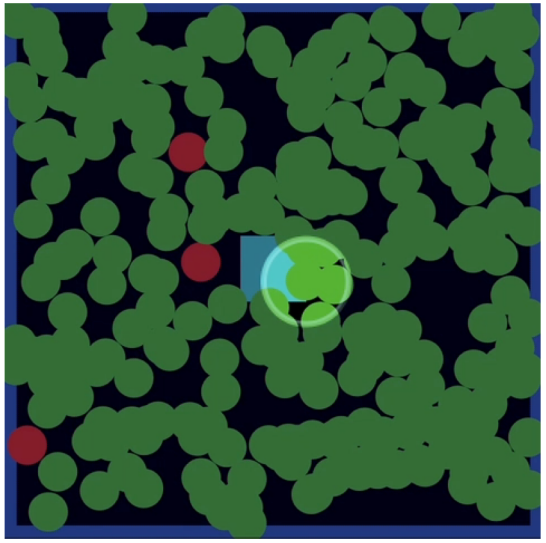
Temporally discounted stimulus sets recruitment decision

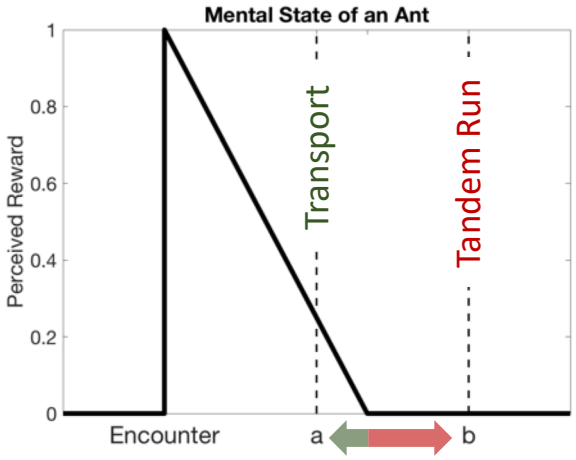




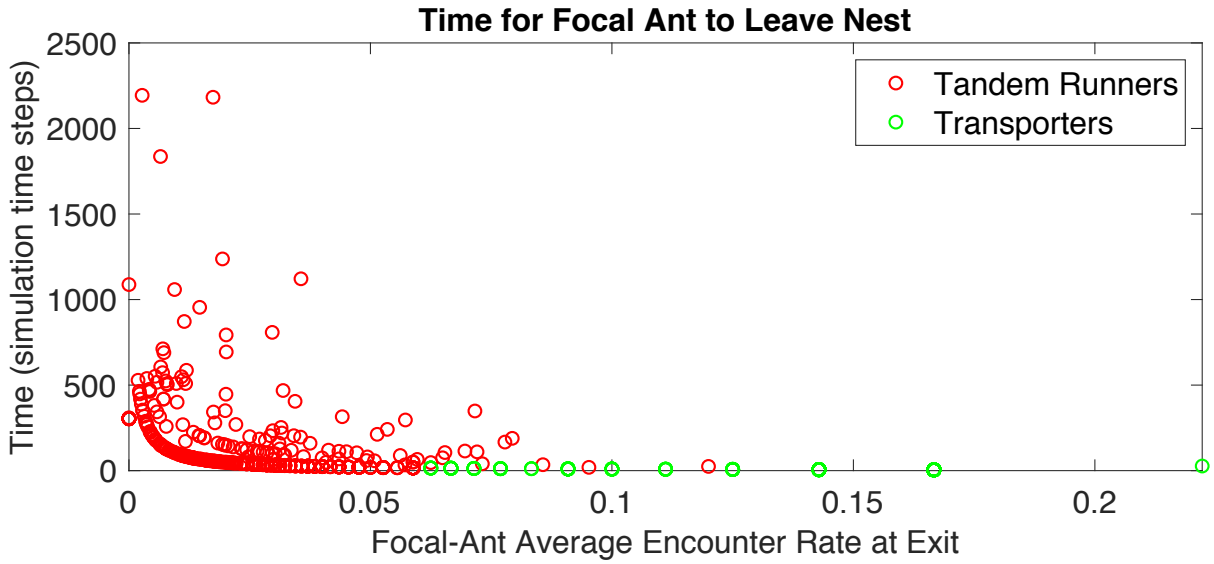
Web version of simulator:
http://bit.ly/bda2018quorum

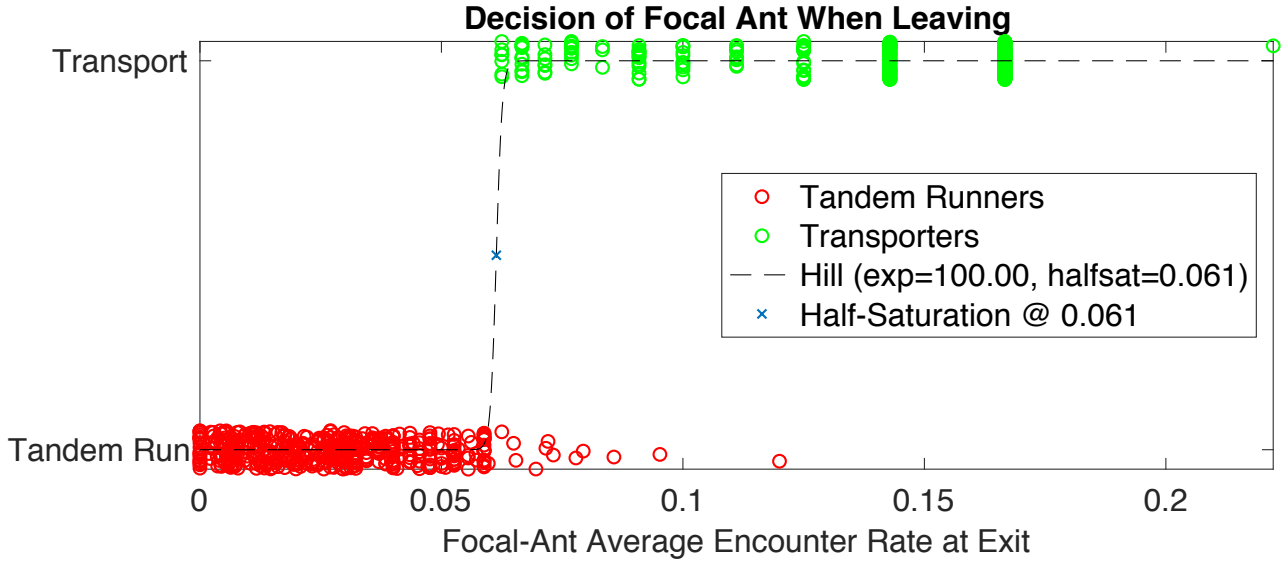




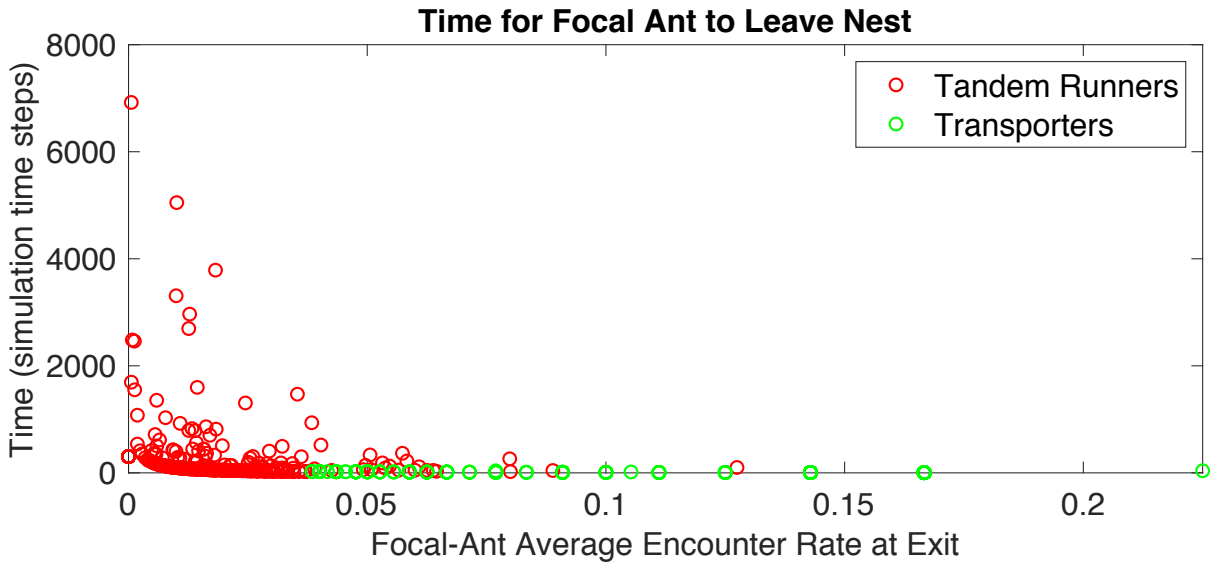


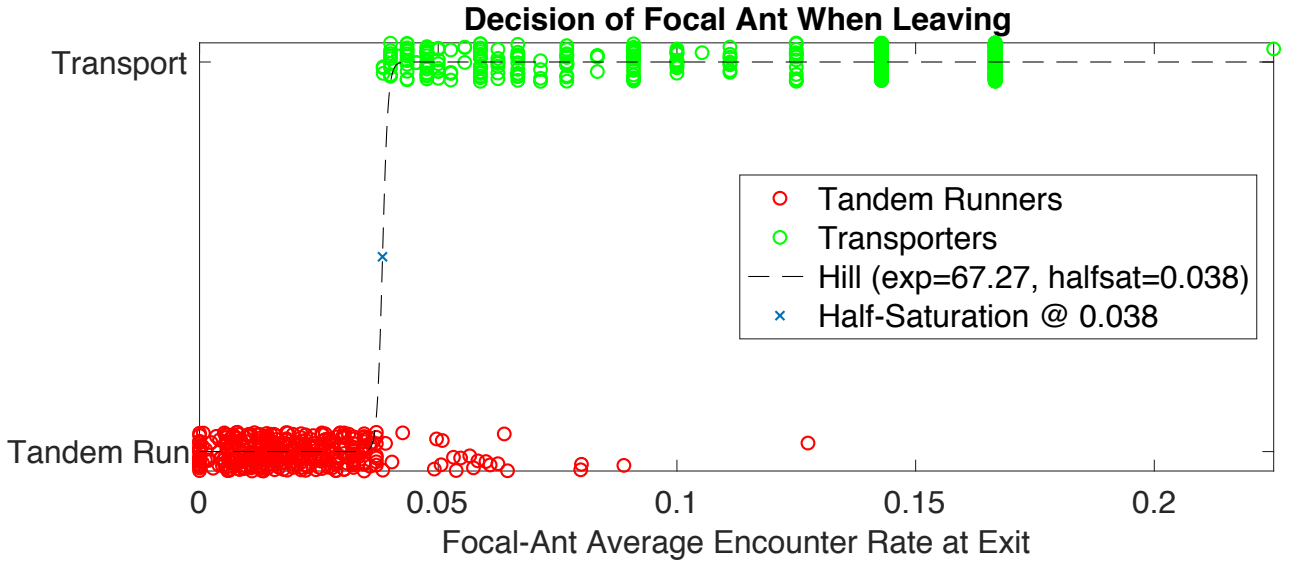
Weak Stimulus (High Discount Rate)



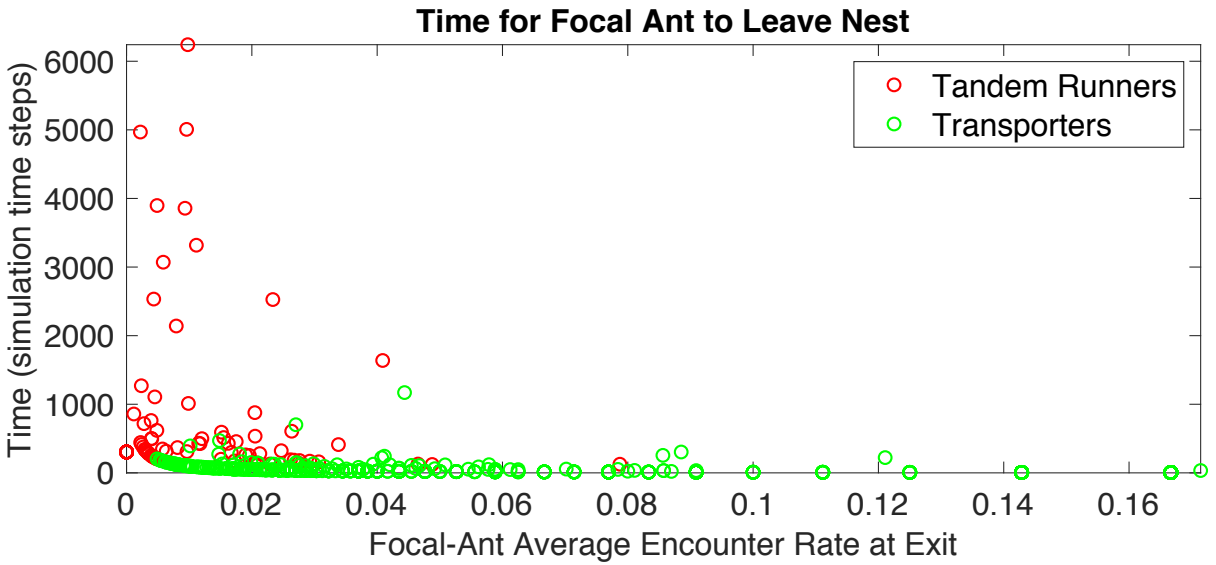


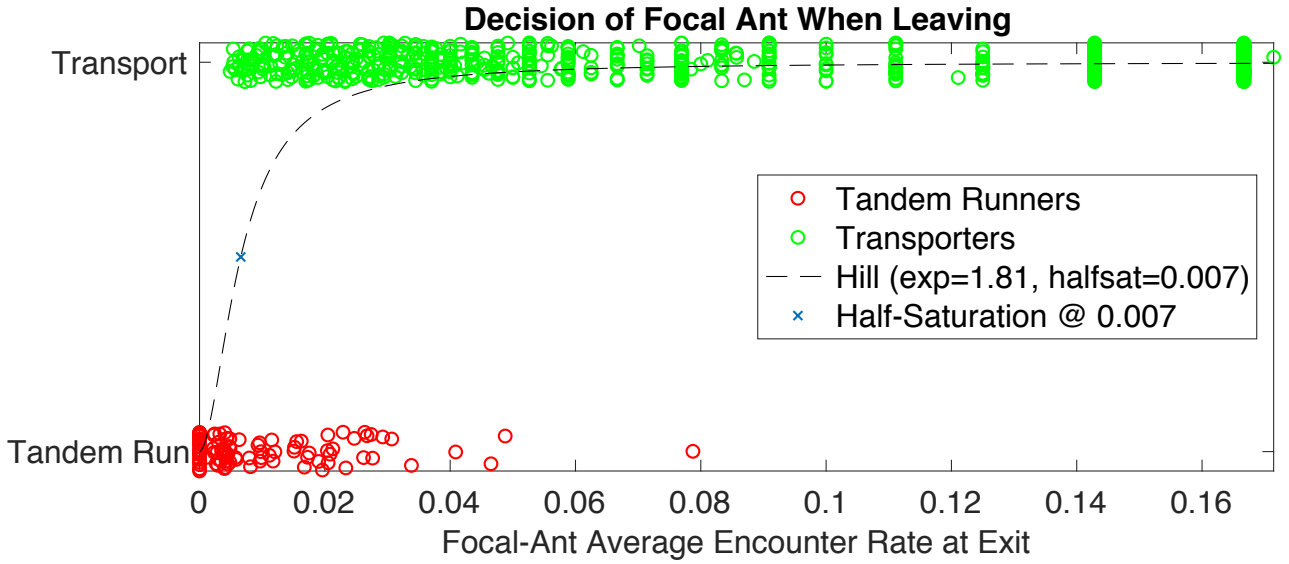
Medium Stimulus (Medium Discount Rate)



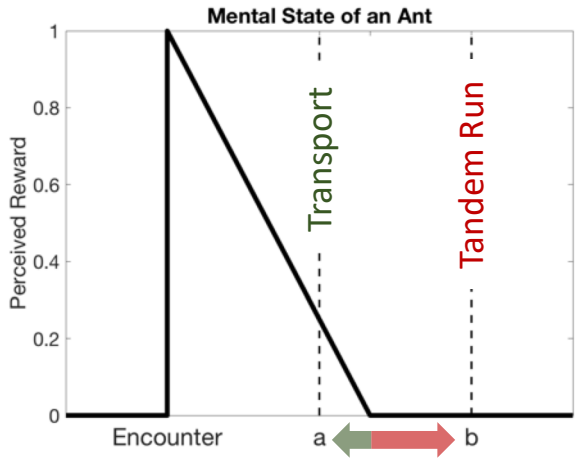


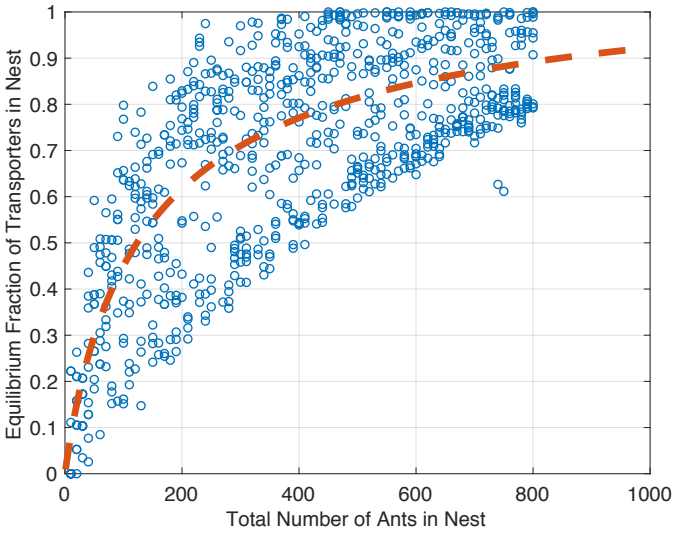
Strong Stimulus (Low Discount Rate)





…also amenable to theoretical analysis.





$$S + S \xrightarrow{e_a} 2R$$

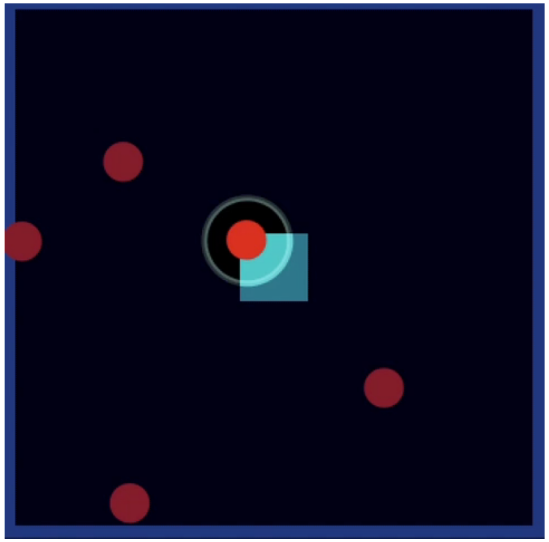
$$S + R \xrightarrow{e_a} 2R$$

$$S + E \xrightarrow{e_e} X_{TR} + E$$

$$R + E \xrightarrow{e_e} X_T + E$$

$$R \xrightarrow{1/\tau} S$$

For take away…



- The ants are an interacting ***ensemble***
- The cavity's physical space is a ***sampler***
- The computational model should be at the level of the **ant–cavity system**

- **More broadly:** Physical spaces provide memory and even computational primitives for free

The Team:

Arizona State University

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Dr. Stephen Pratt

Dr. Gabriele Valentini

Jake Hanson

Acknowledgements:

NSF

NSF PHY-1505048

Thanks to the **BDA 2018** organizers!

For More Information:

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tpavlic@asu.edu

Web version of simulator:
http://bit.ly/bda2018quorum

"Any questions?"