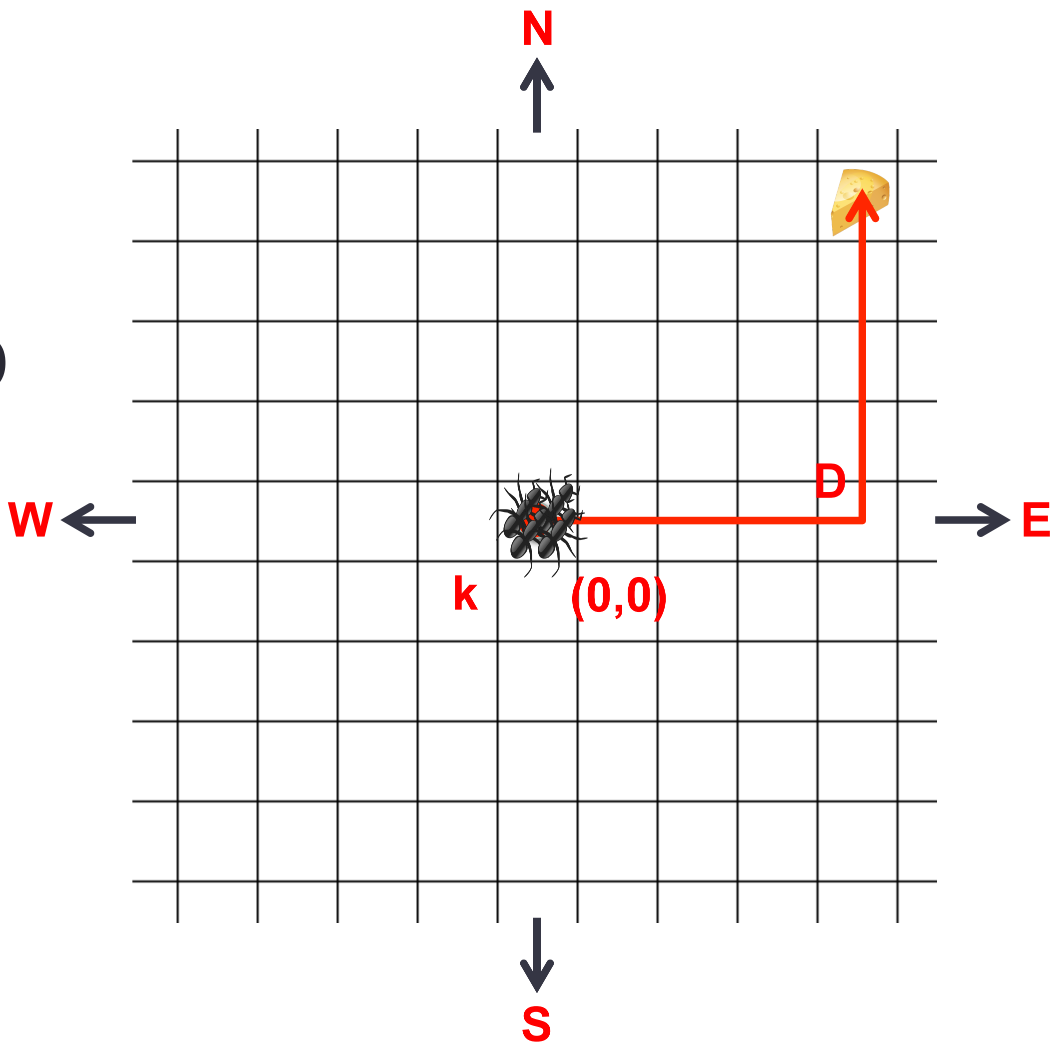
Ants Nearby Treasure Search

- Infinite grid
- k ants
  - Initially at the origin
- Food at distance D

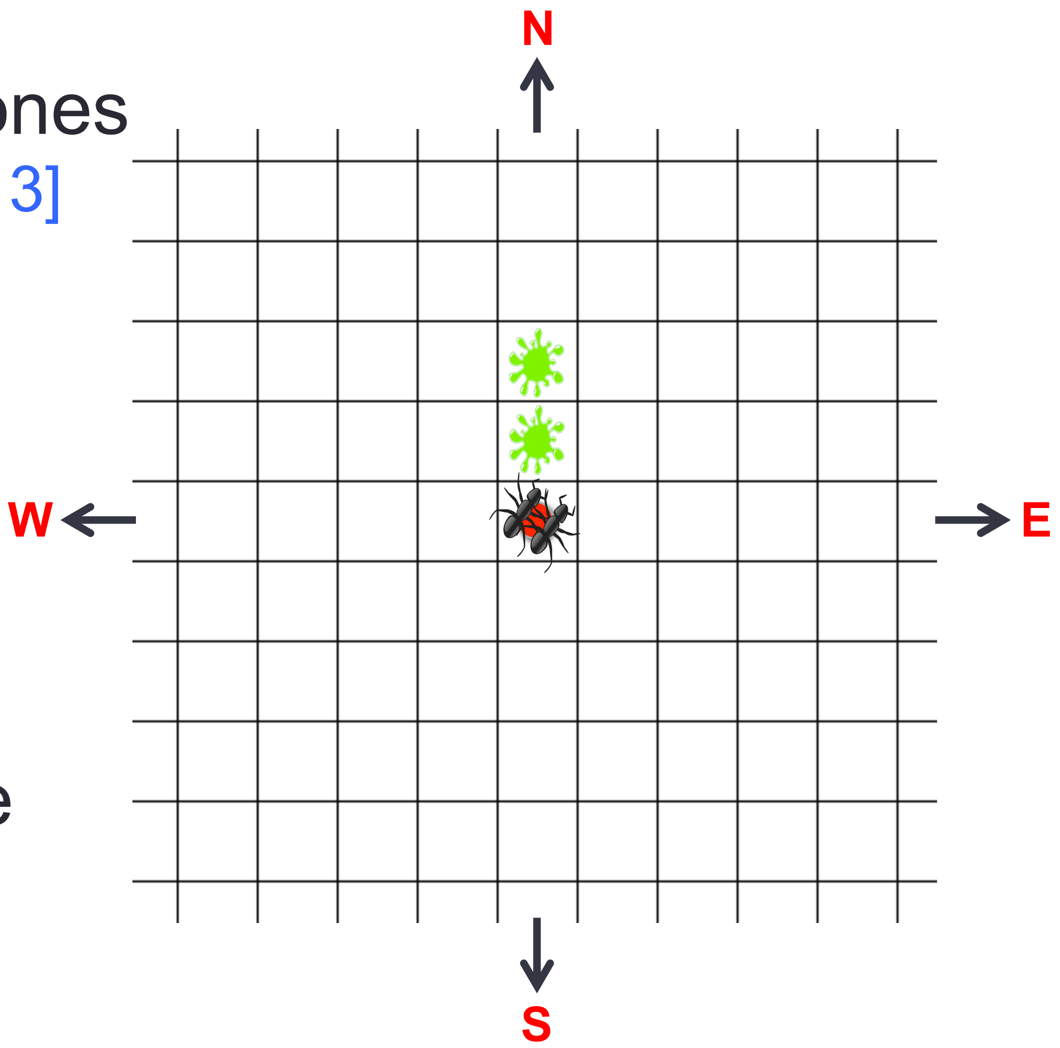
- Ants have to find the food

- Optimal run-time:
  $\Omega(D + D^2/k)$
  [Feinerman, Korman, Lotker, Sereni, 2012]



Pheromones

- Ants emit pheromones [Lenzen, Radeva, 2013]
  - Or not
- And sense them
- No other communication
- Biological resource
- Goal: minimize pheromone count



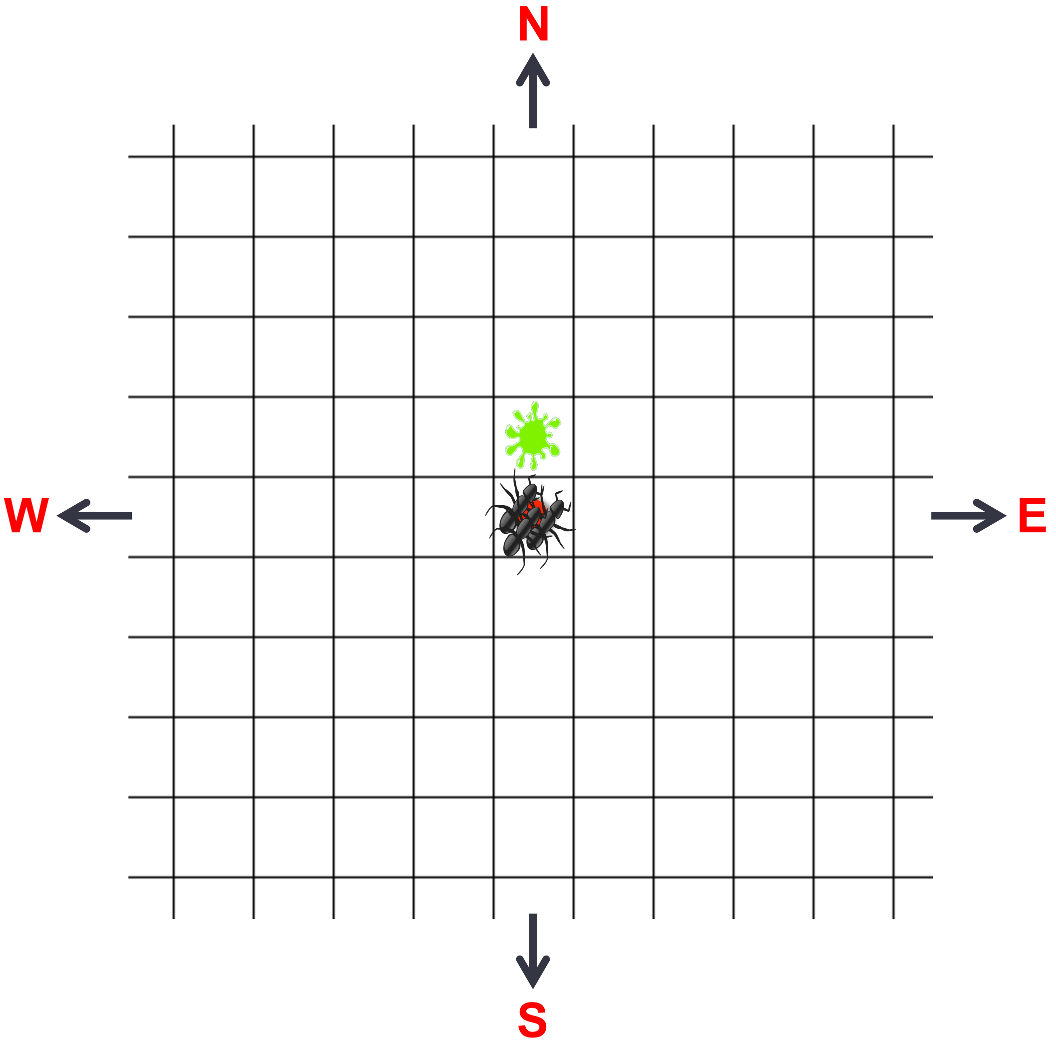
Ground Rules

- Every ant runs same algorithm (locally)
  - With same initial state

- Only uniform algorithms,
  ants have no knowledge of:
  - k, total number of ants
  - D, distance to the food

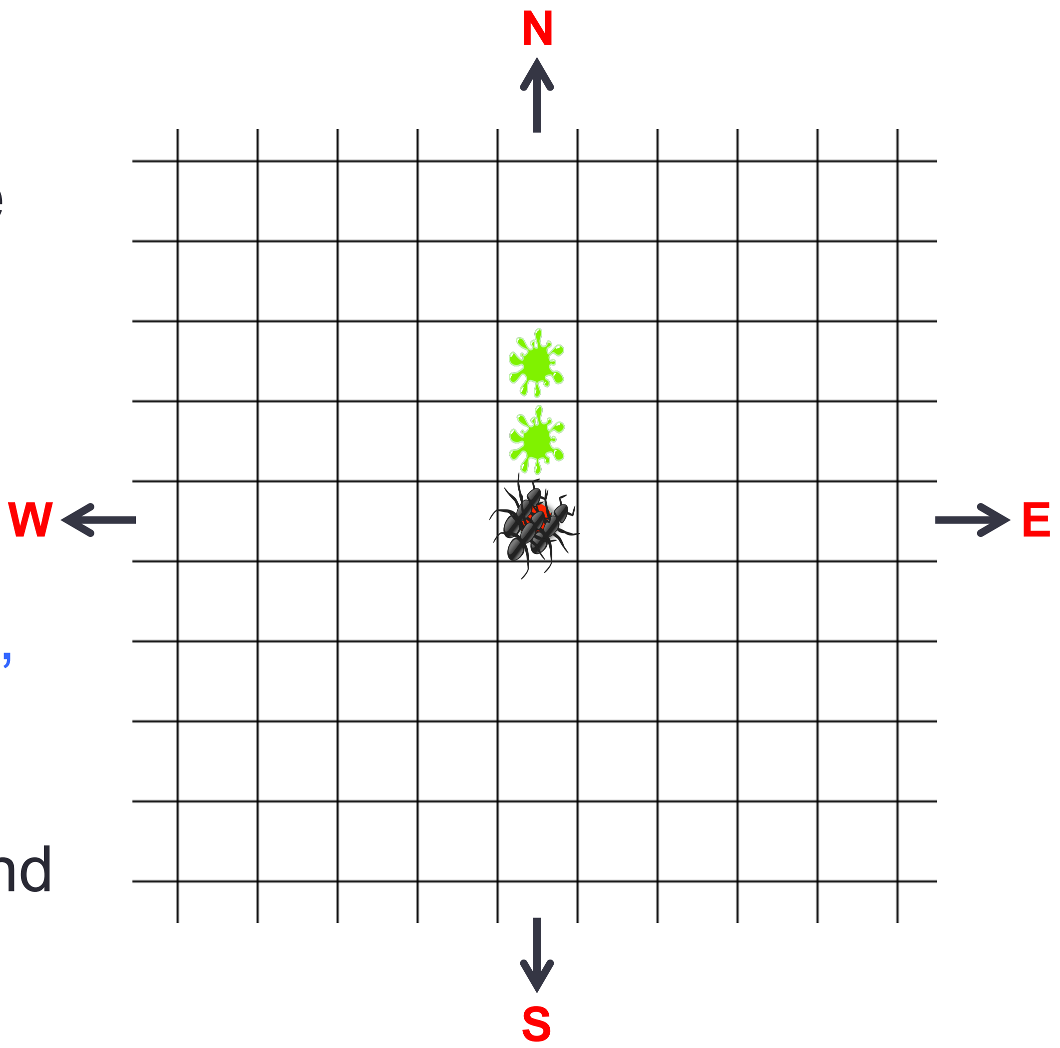
Synchronous Model

- Rounds:
  all ants move once per round



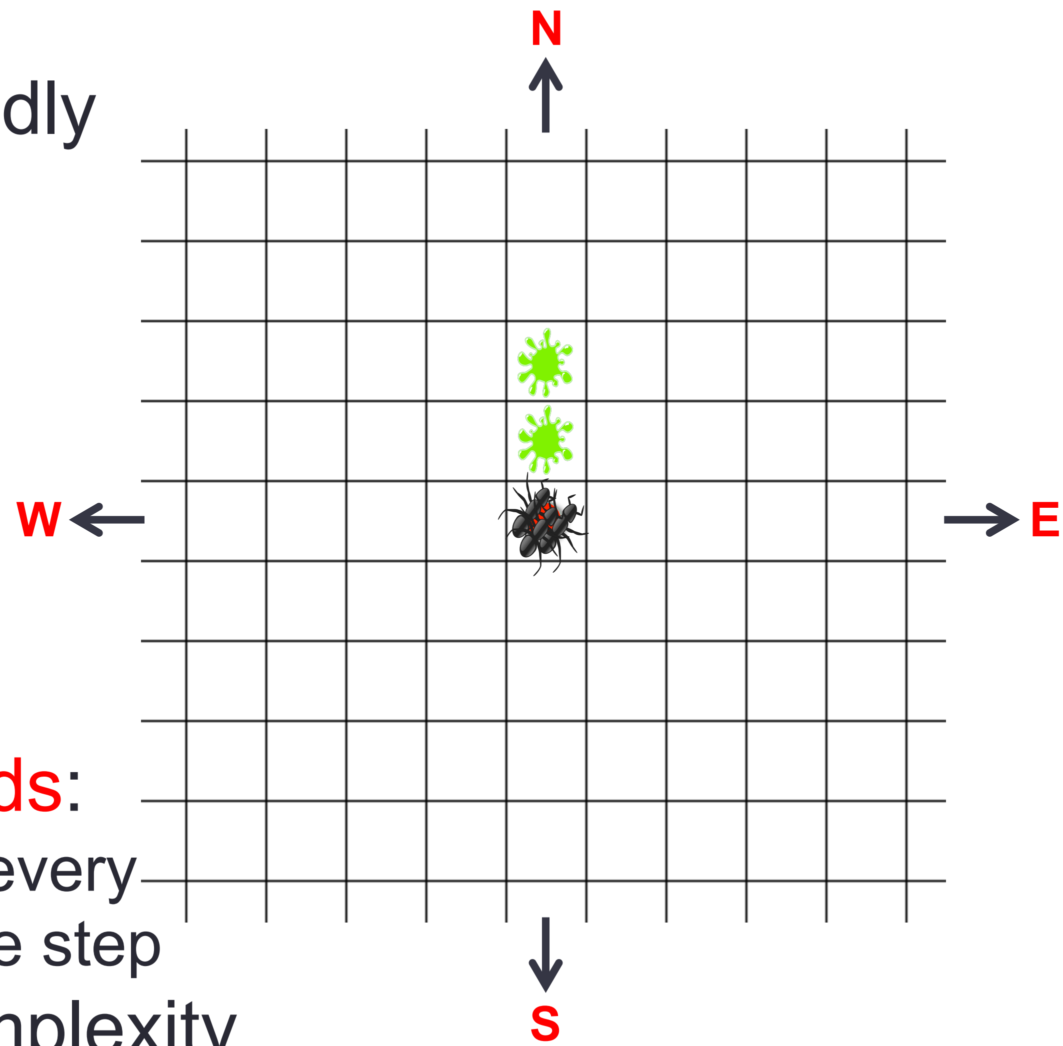
Synchronous Model

- Rounds:
  all ants move once per round
- Assumption: ant emission scheme [Emek, Langner, Uitto, Wattenhofer, 2013]
  - At most one ant is emitted in each round



Asynchronous Model

- Adversary repeatedly schedules one ant
- Test&Set:
  - Sense and emit a pheromone is one atomic step
- Definition of Rounds:
  - Round ends when every ant took at least one step
- Only for (time) complexity



Ants Models

- FSM: Finite State Machines
  Constant size memory

- TM: Turing Machines
  Unlimited memory

- Both deterministic

Results

	Lower Bound	Algorithm
FSM (Deterministic)	$\Omega(D)$ pheromones to find the food	$O(D)$ pheromones $O(D + D^2/k)$ time
TM (Deterministic)	$\Omega(k)$ pheromones for optimal run time	$O(k)$ pheromones $O(D + D^2/k)$ time

Previously known: $O(D^2)$ pheromones [Lenzen, Radeva, 2013]

Results hold for Synchronous and Asynchronous models

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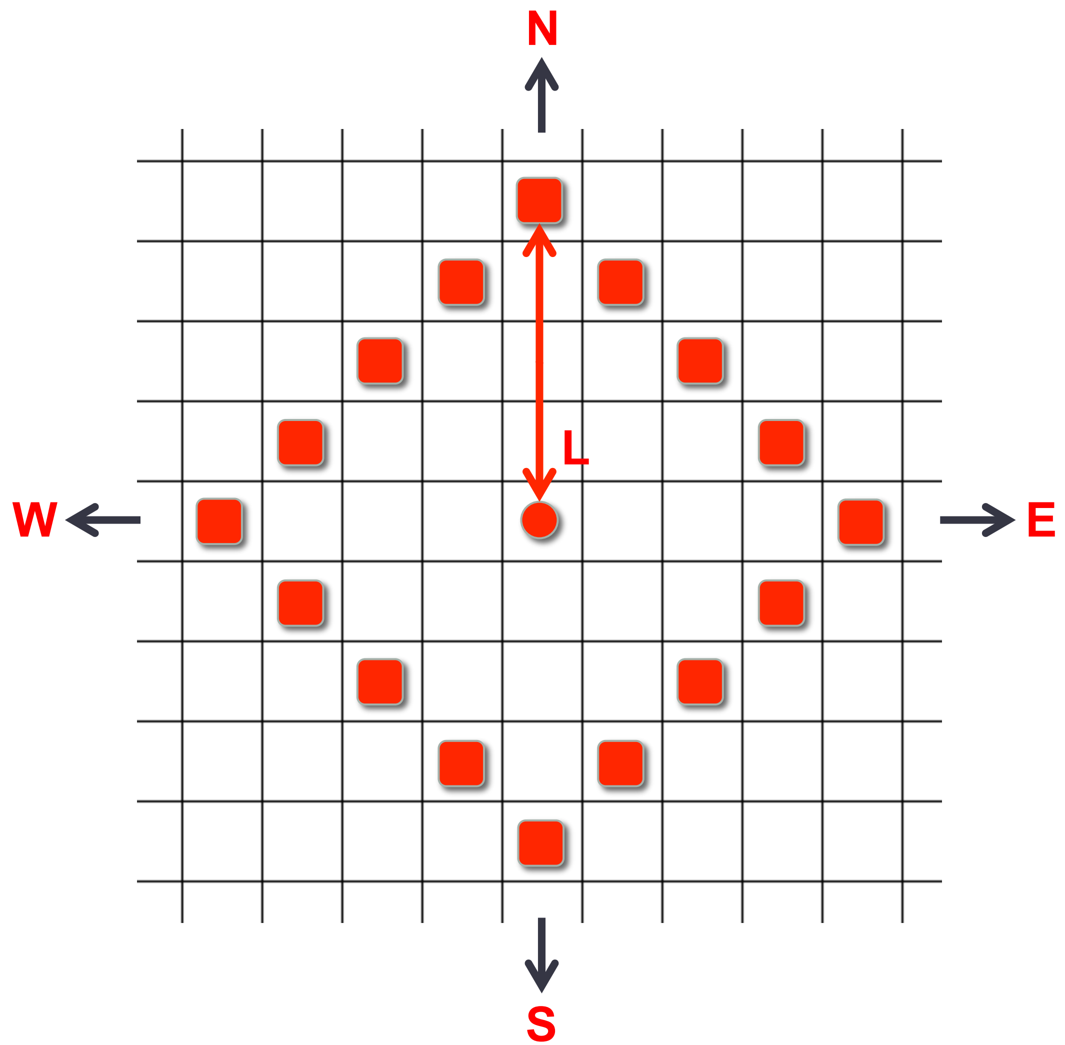
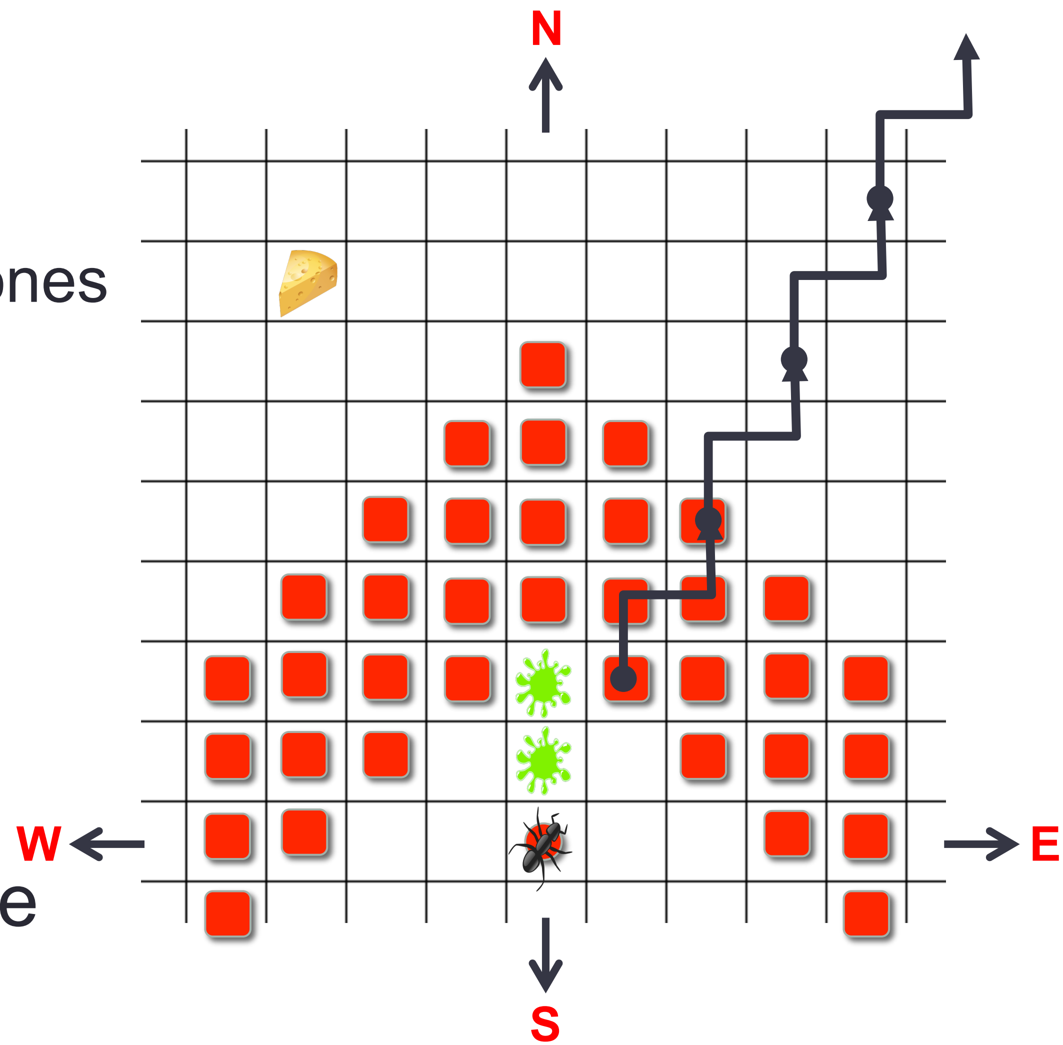
Layers

- Definition: layer L
  - All grid cells at distance L from origin



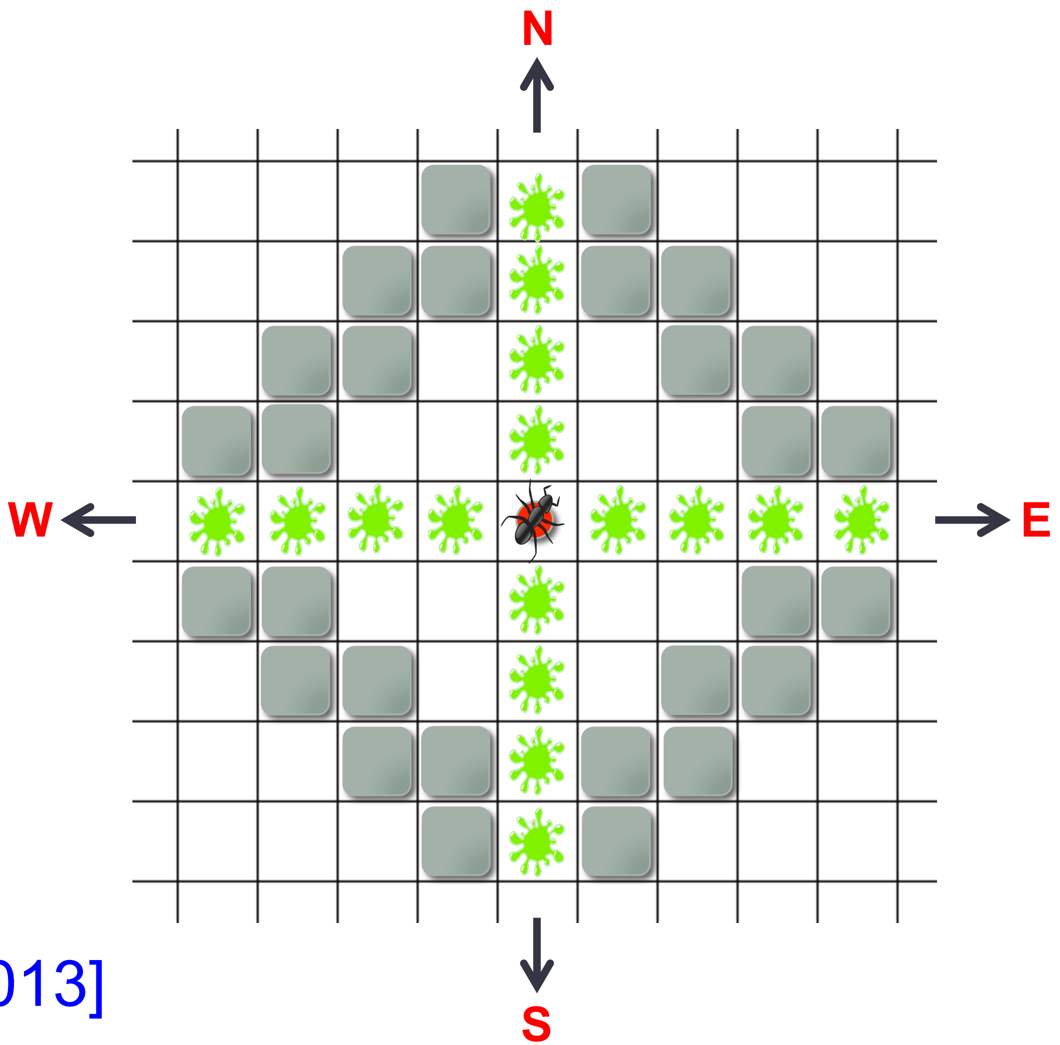
FSM Need Ω(D) Pheromones

- Assume FSM with S states
  - Uses o(D) pheromones
- S+1 consecutive pheromone-free layers exist
- Path starts and ends in same state
  - Infinite loop



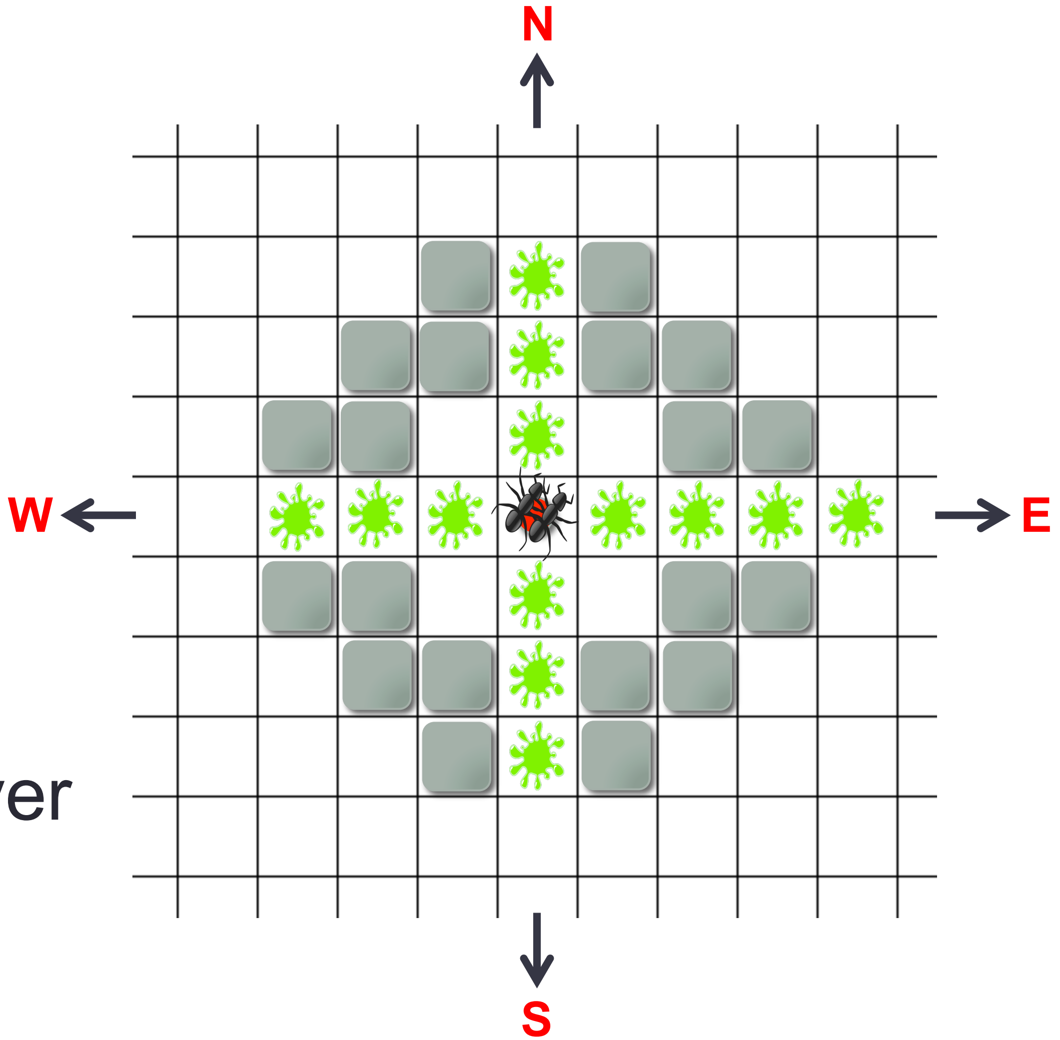
FSM Algorithms

- Problem:
  FSM can't count
- Solution:
  Use pheromones as turning points
- Similar to the idea of guides [Emek, Langner, Uitto, Wattenhofer, 2013]



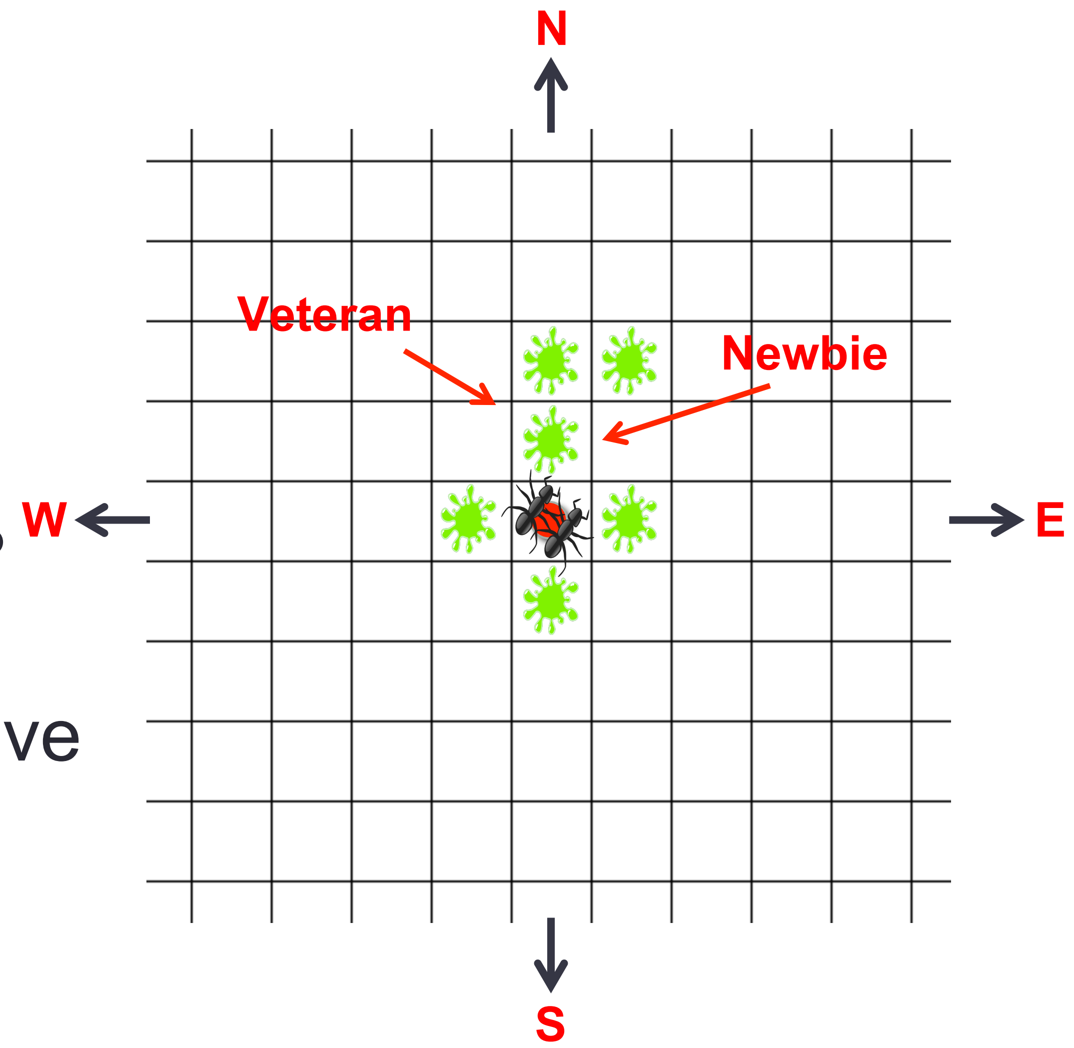
Asynchronous FSM Algorithm

- Mark E, S, W, N
- Explore from N
  - N never longer than E, S or W
- Test&Set prevents multiple ants from exploring same layer



Synchronous FSM Algorithm

- Emission scheme breaks initial symmetry
- But what happens if two ants collide?
- Veteran ants behave differently than Newbie ants



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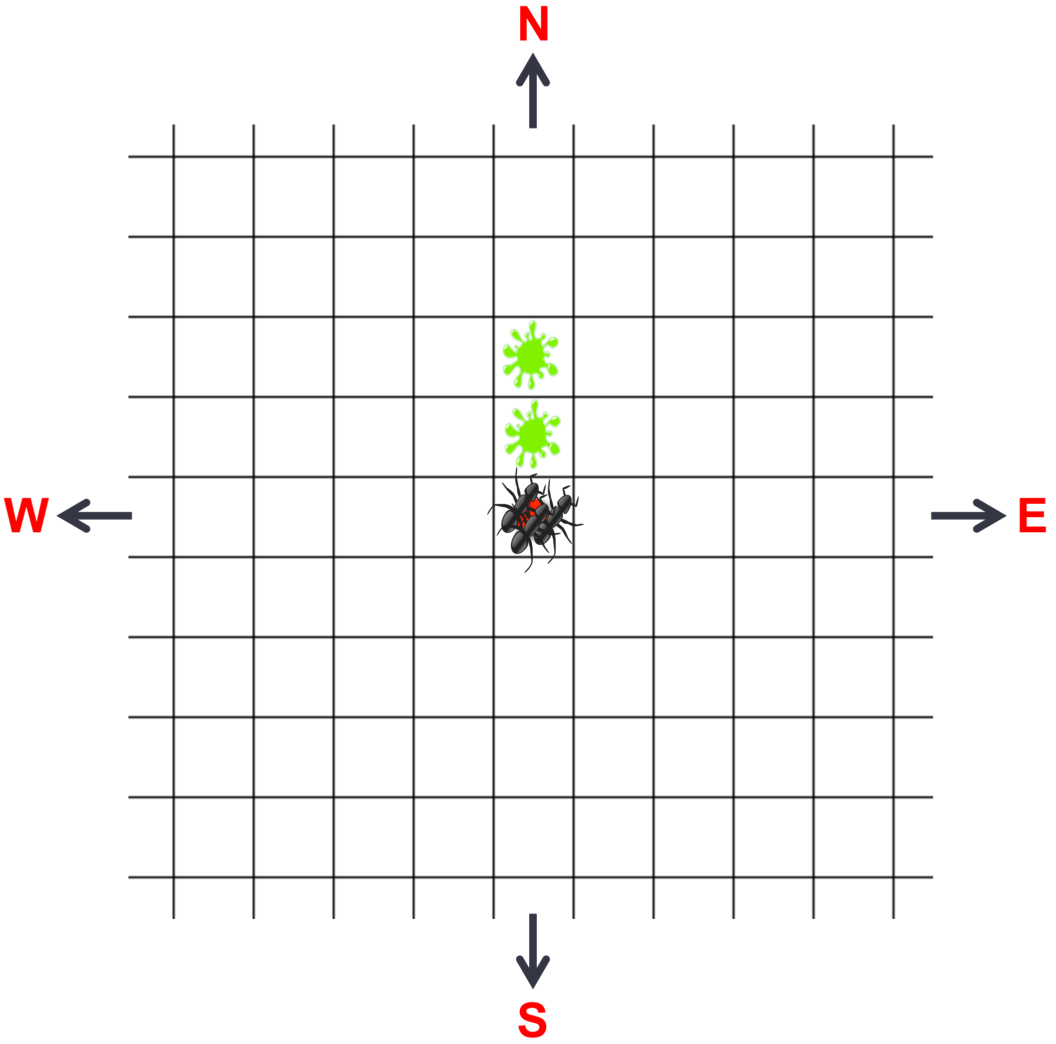
Results hold for Synchronous and Asynchronous models

Async TM Need Ω(k) Pheromones

- Assume one ant does not emit pheromones

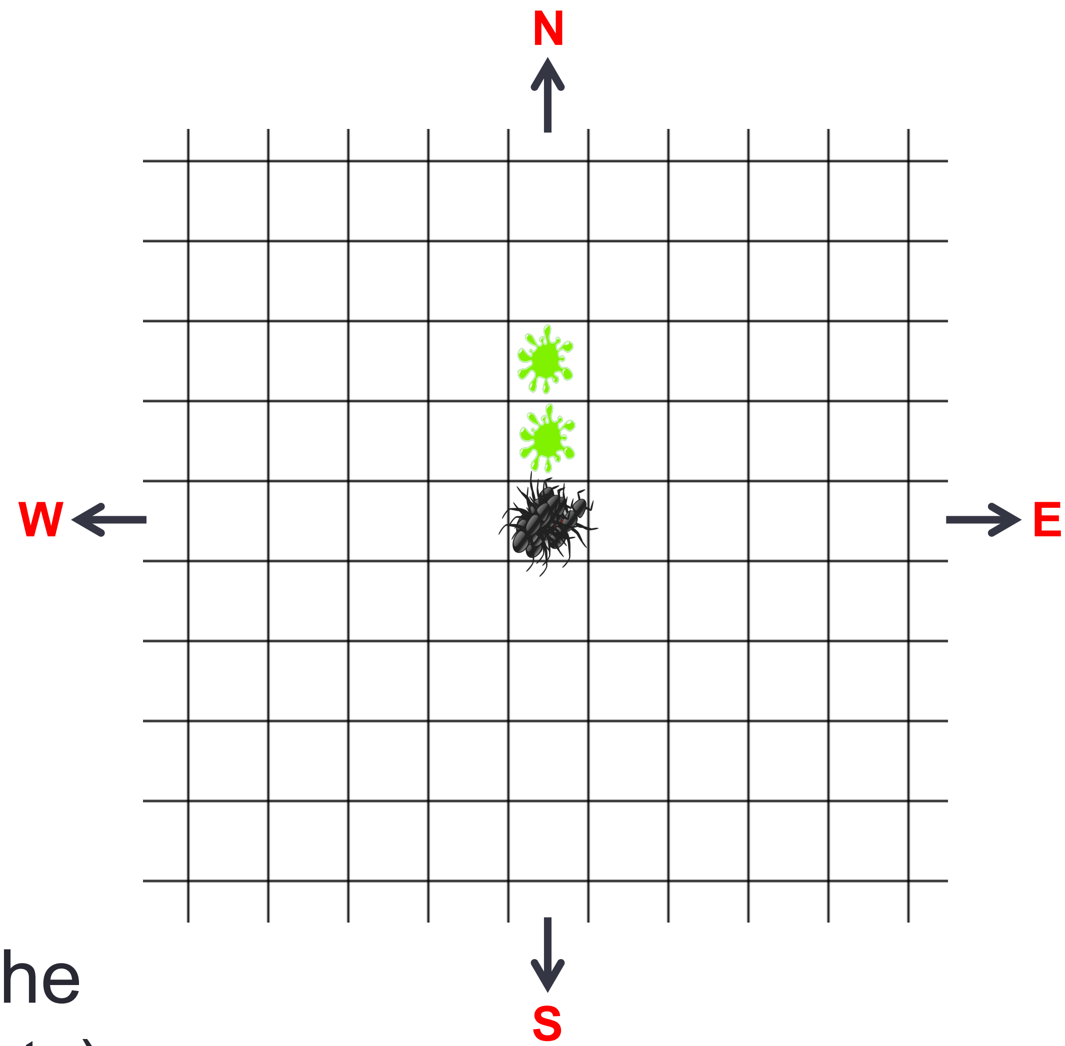


Async TM Need Ω(k) Pheromones

- Assume one ant does not emit pheromones

- Consider same scheduling but with extra ants
  - All new ants follow that one ant

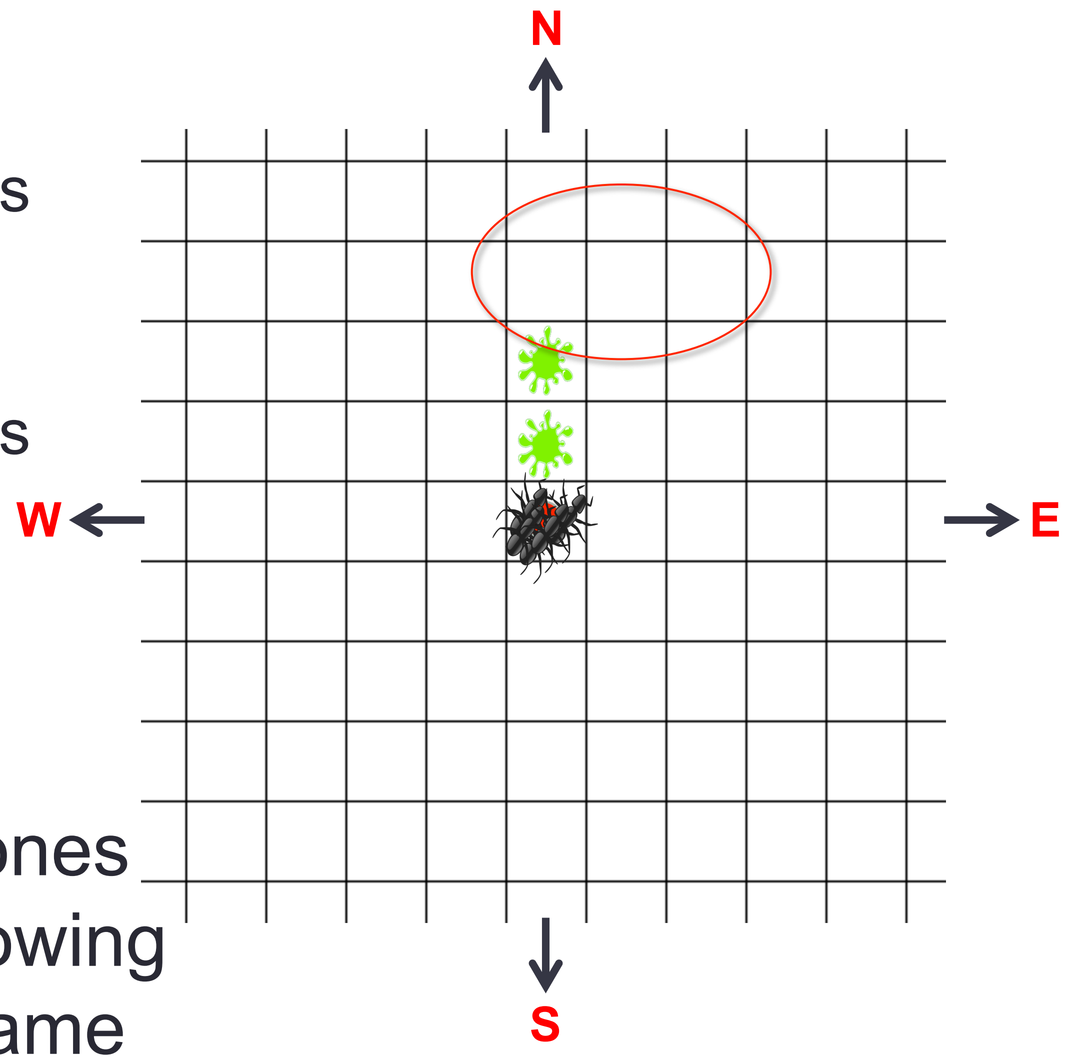
- Runtime remains the same (but more ants)



Sync TM Need Ω(k) Pheromones

- Emit one ant
  - Until all pheromones are placed
- Emit second ant
  - Until all pheromones are placed
- Continue
  - Delay is constant

- If no new pheromones are placed, all following ants behave the same

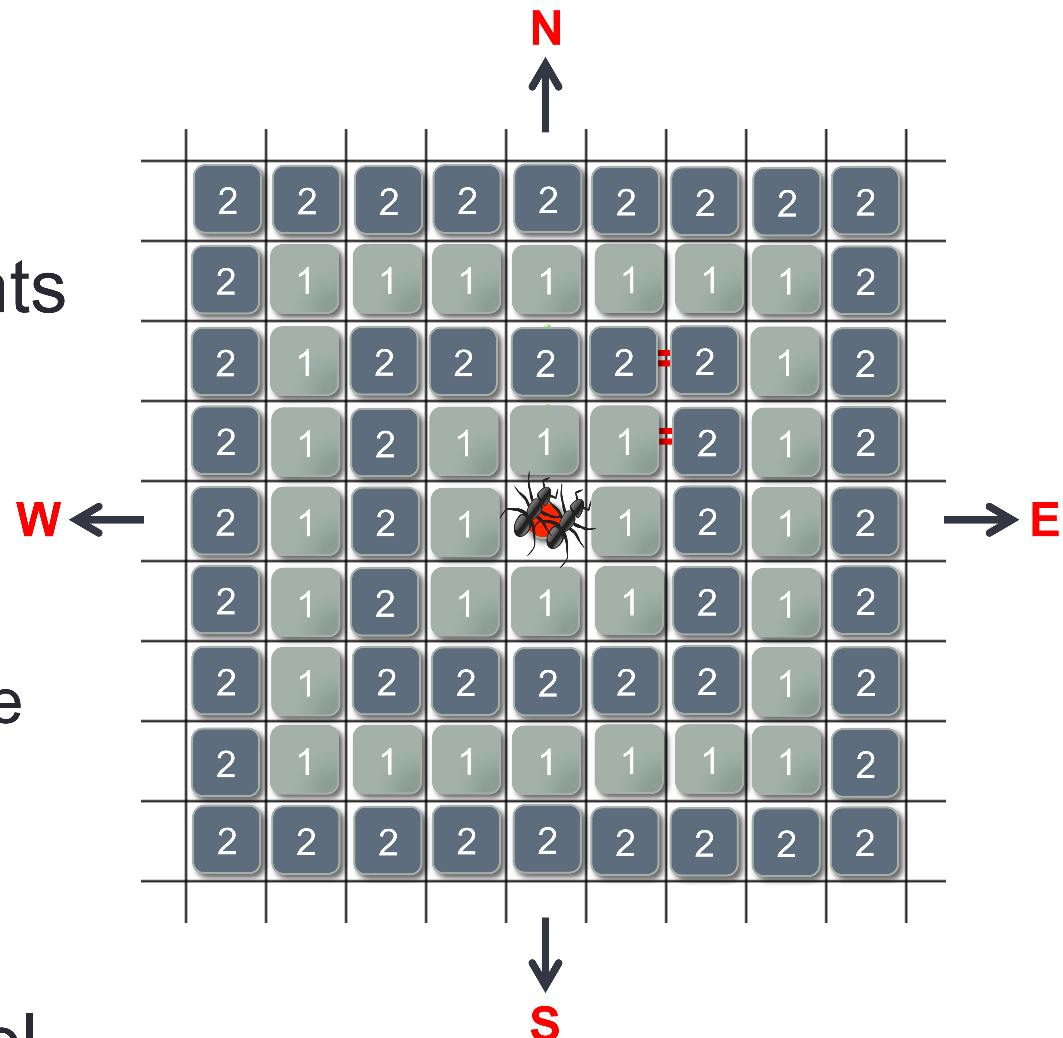


Asynchronous TM Algorithm

- TM can count!
- Use pheromones to assign IDs to ants

- Static partition
  - Explore layers L = ID (mod Total)
  - Occasionally update estimated Total

- Also works for the synchronous model



Future Directions

- Fault tolerance (with pheromones)
- Employ randomization
  - To implement emission schemes
  - To further reduce pheromone counts
- Avoid Test&Set semantics
- Direct rest of ants to the found treasure
  - And/or back to the nest

Thanks

Questions?