Behavior Modes for Randomized Robotic Coverage

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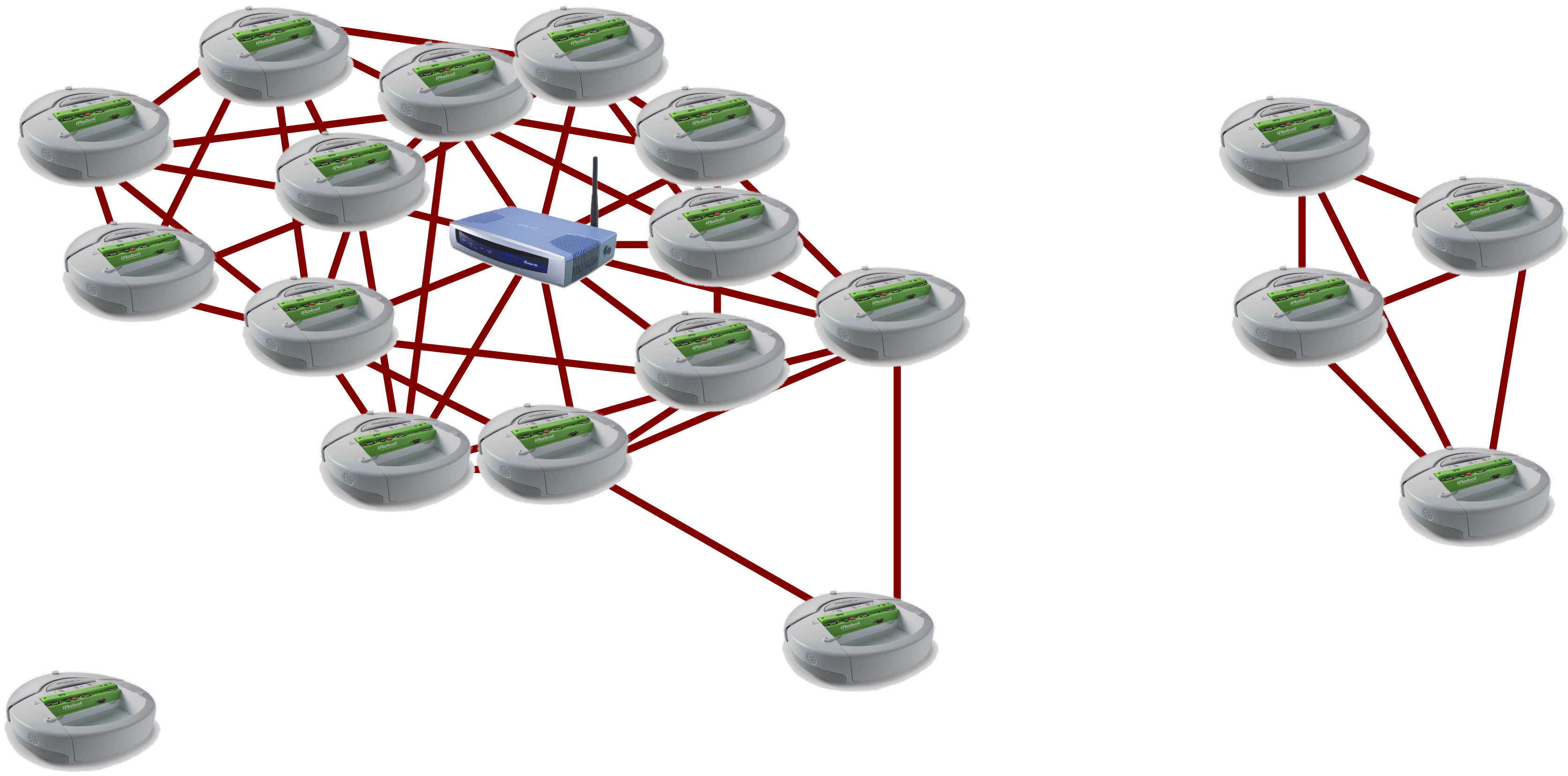
BBN TECHNOLOGIES

Coverage

From some initial distribution, move to provide "good" network coverage over a large area



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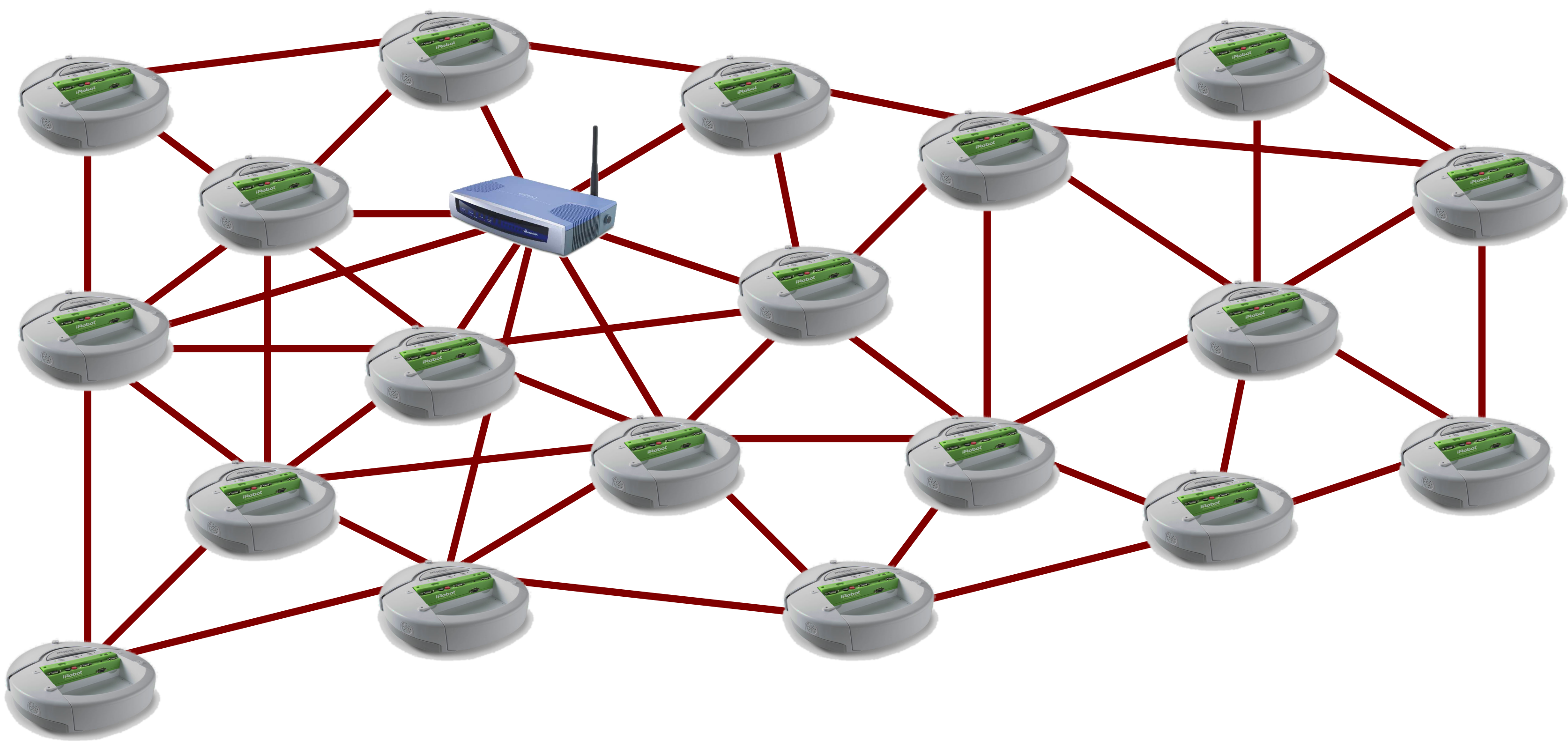


How much coordination is necessary?

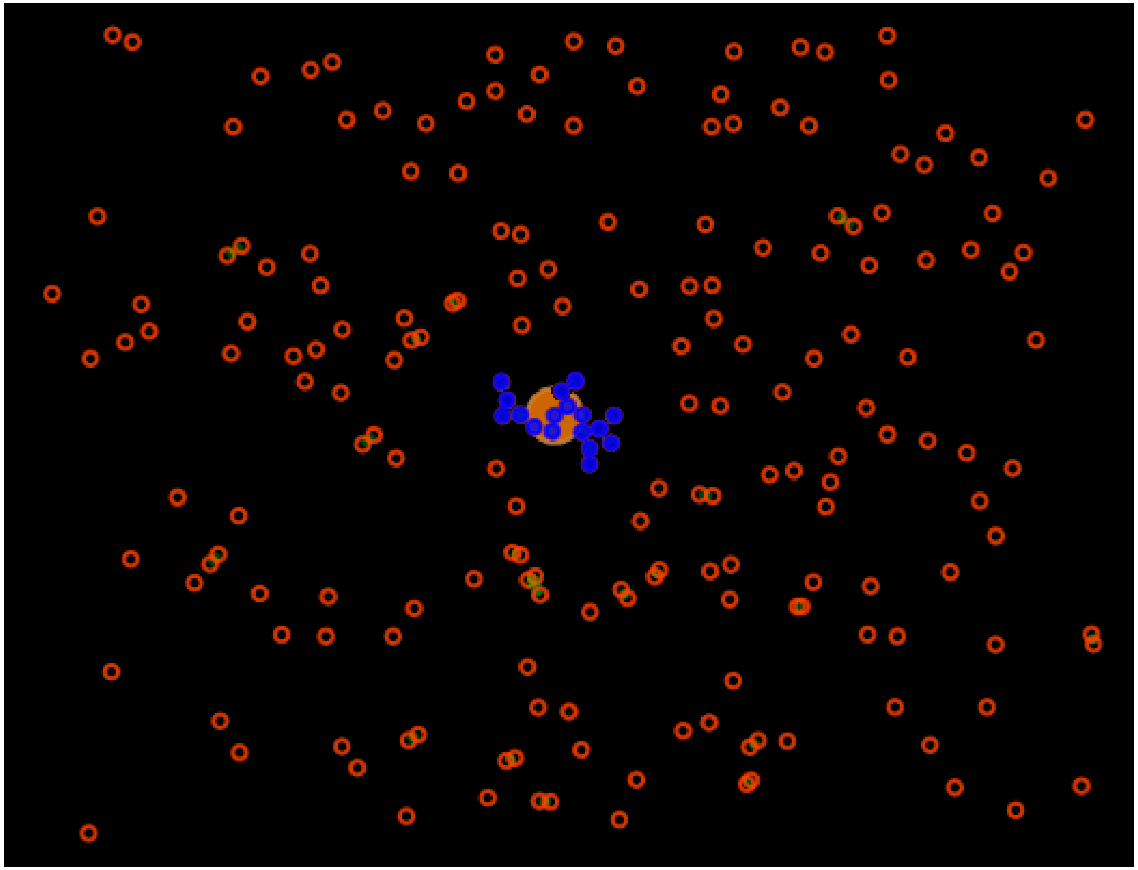
Randomized Coalescence Algorithm

For robot *i*:

IF	$\alpha \le \|nbrs(i)\| \le \beta$
	AND **connected to seed**
THEN	**do nothing**
ELSE	**move** v · Wt
	(where Wt is a Wiener process)

- Poduri & Sukhatme (DLA) $O(1/\sqrt{n})$
- Correll (Generalized)

But does it work?



```
proto -m -l -c "(mov (coalesce (red (= (mid) 0)) 1 5 15))" -n 200 -r 2 -s 0.1 -dist-dim -40 40 -40 40 -fixedpt 0 0
```

Preview of Results

- Five qualitative domains of behavior
- Random navigation is not sufficient
- Some long-range coordination is necessary

And now the details...

Randomized Coalescence Algorithm

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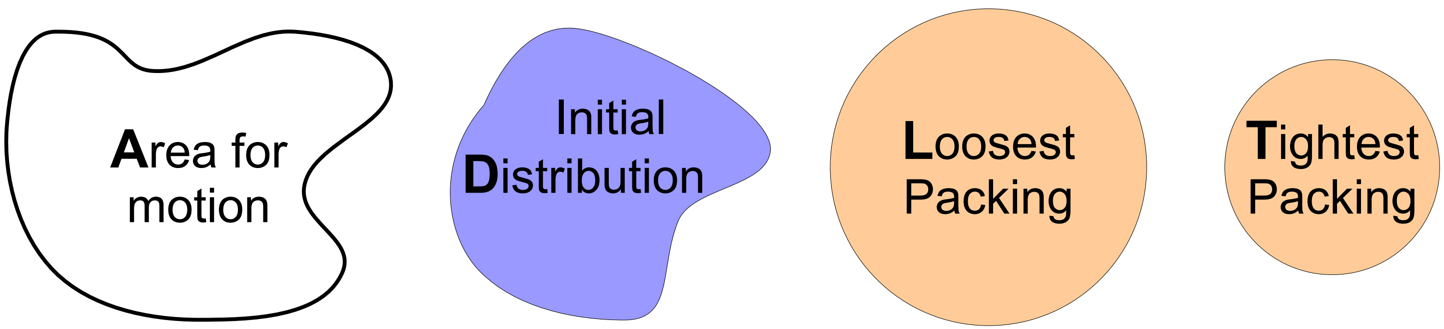
```
(def coalescence (gateway b a max)
    (if (muxor gateway
               (muxand (< (hop-gradient gateway) max)
                       (and (>= (num-nbr) b)
                            (<= (num-nbr) a))))
        (all (blue 1) (tup 0 0))
        (brownian)))
```

Network Model

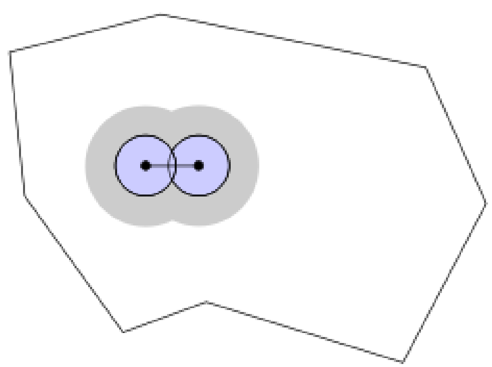
- *n* nodes, radius *r* unit disc communication



Bounds on Convergence Area

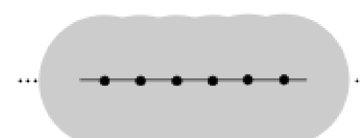
Tightest

$$T \geq \frac{\pi r^2 n}{4(\beta+1)}$$



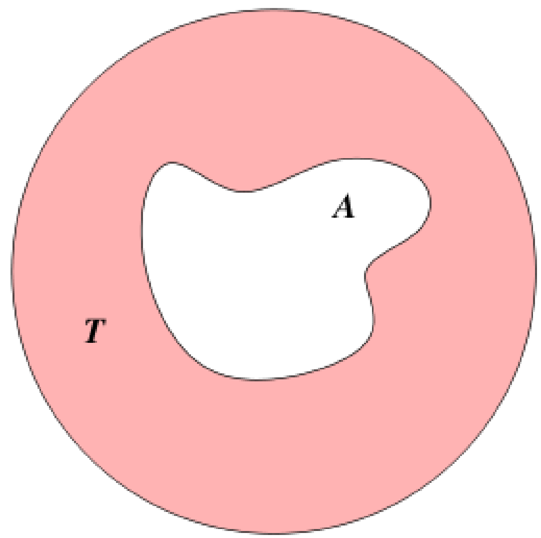
Loosest

$$L \leq n \frac{4r^2}{\alpha}$$



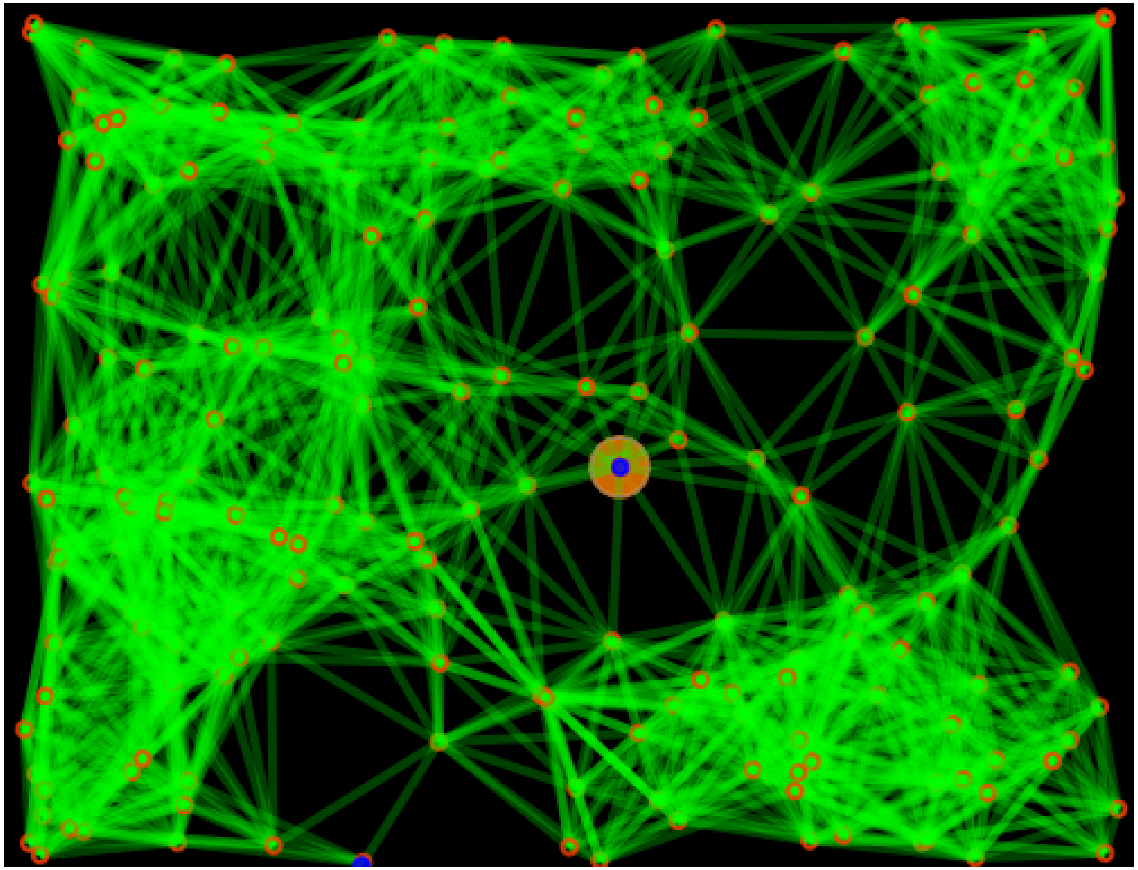
(assuming unit disc connectivity w. radius *r*, ignoring edge effects)

Impossible Conditions



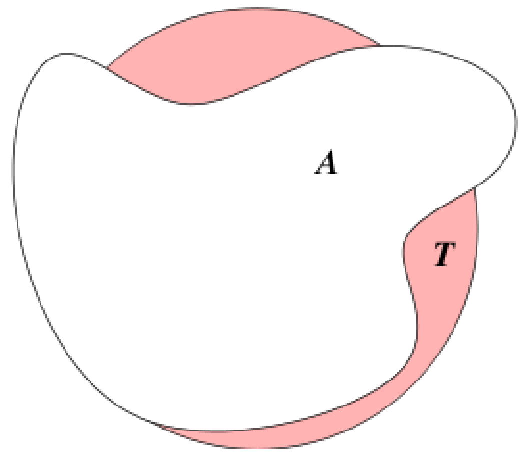
Tightest possible distribution is larger than area

Impossible Conditions



```
proto -w -m -l -c "(mov (coalesce (red (= (mid) 0)) 1 5 15))" -n 200 -r 20 -s 0.1 -fixedpt 0 0
```

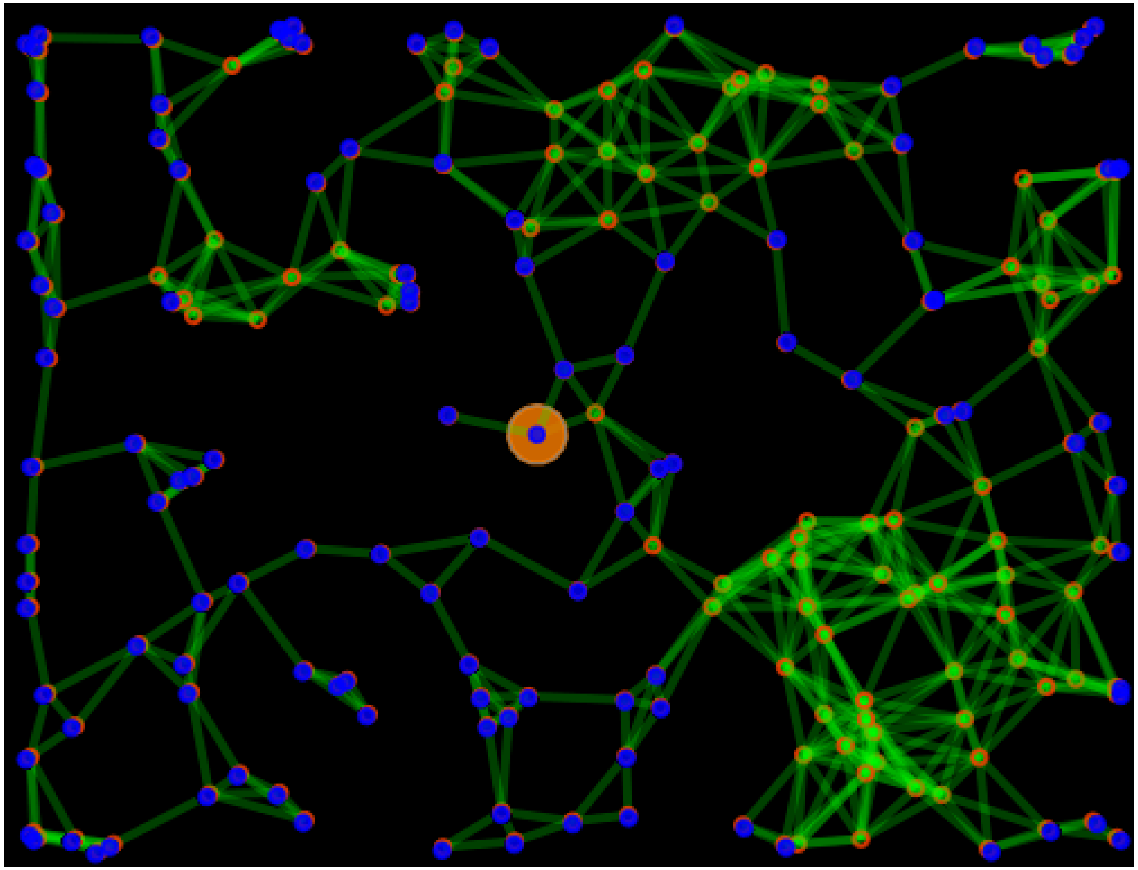
Critical Conditions



e.g. 2 robots in a 1D space, diam=2r+ε, α=β=1:

P(converge) < ε/(2r+ε)

Critical Conditions



```
proto -w -m -l -c "(mov (coalesce (red (= (mid) 0)) 1 5 15))" -n 200 -r 11 -s 0.1 -fixedpt 0 0
```

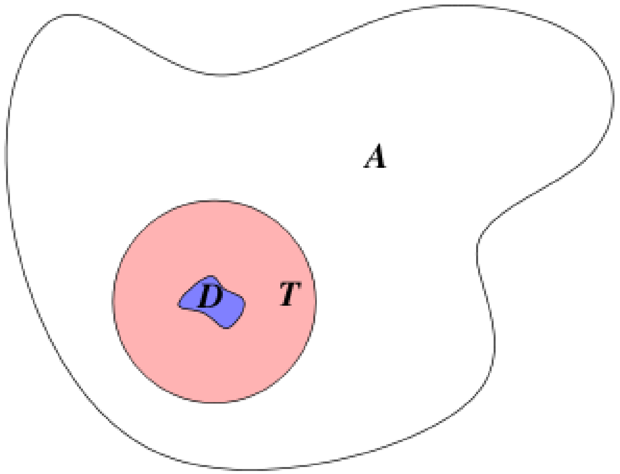
The Importance of Initial Conditions

- Consider the initial distribution of robots D:
  - Previous simulations have used A≈D≈[T,L]
  - More realistic: box-of-bots (D<<T), airdrop (D>>L)
- Random Motion = Diffusion
  - $O(d^2)$ time to move expected distance d

Diffusion is slow!

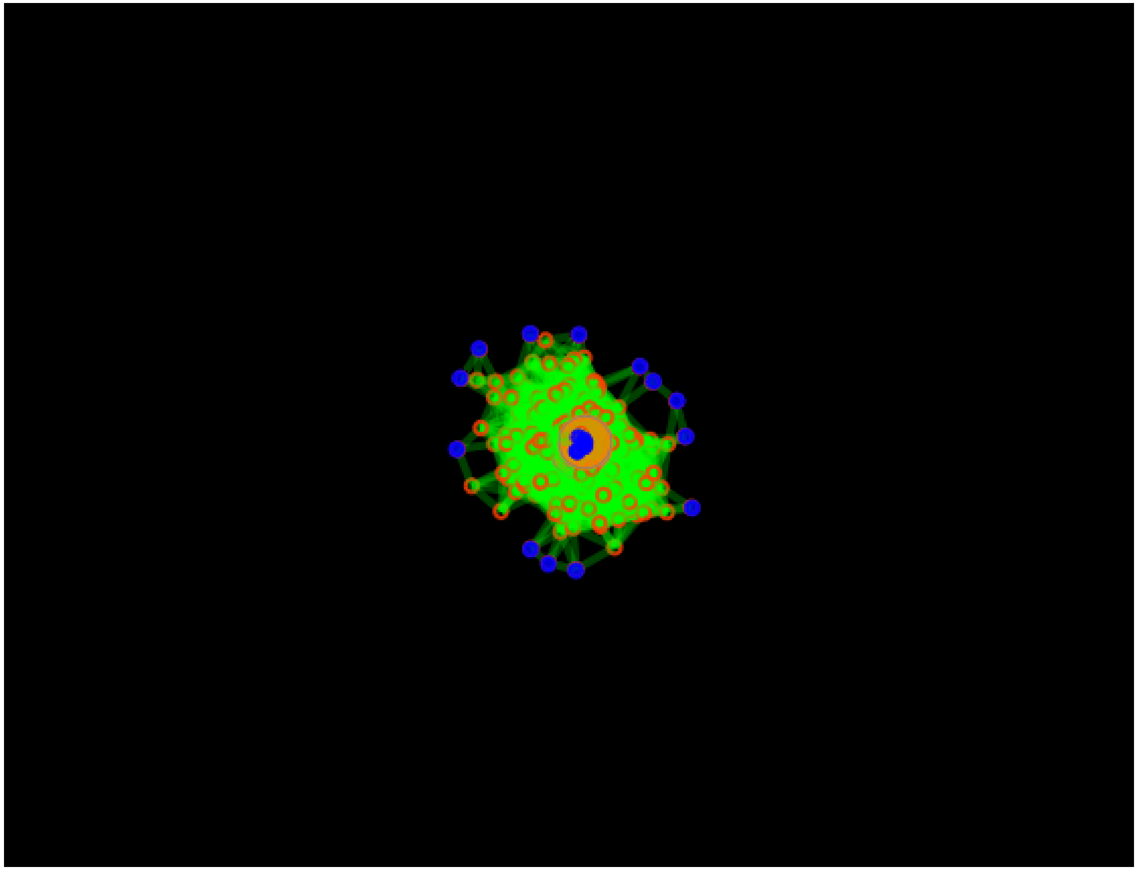
Dispersion Dominated

Consider opening a box full of robots:



Random walk expected to move $\sqrt{T}$ in $\Omega(T)=\Omega(n)$ time

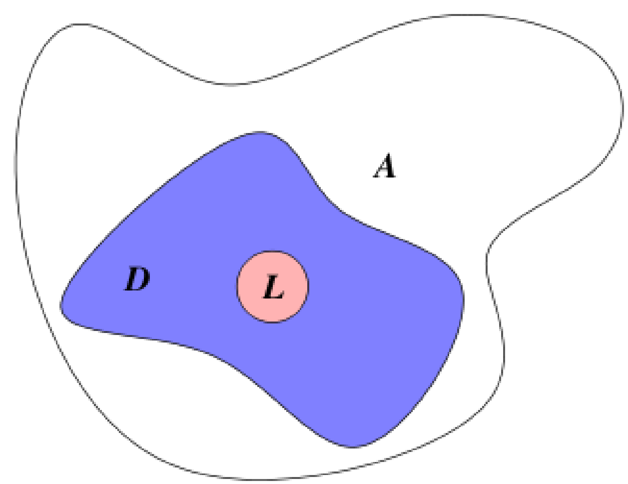
Dispersion Dominated



```
proto -w -m -l -c "(mov (coalesce (red (= (mid) 0)) 1 5 15))" -n 200 -r 5 -s 0.1 -dist-dim -5 5 -5 5 -fixedpt 0 0
```

Discovery Dominated

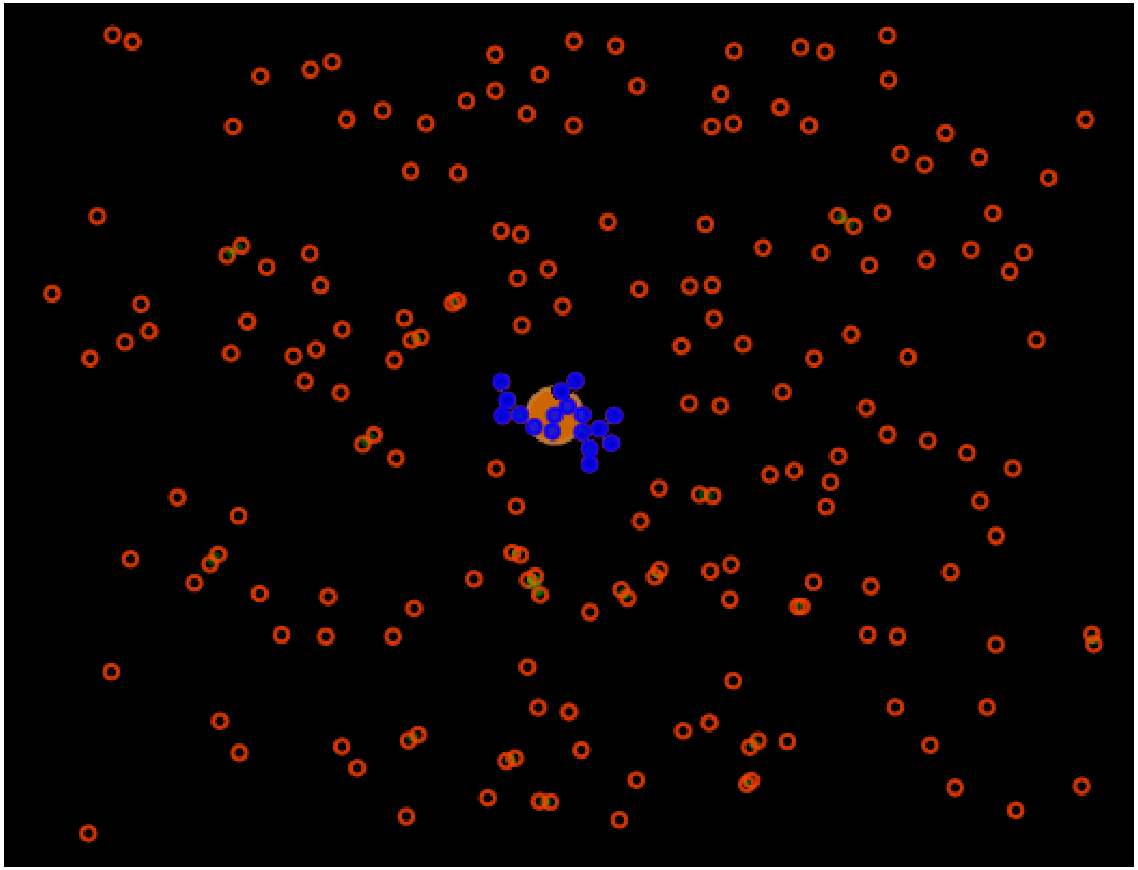
Consider air-dropped robots looking for the seed:



Random walk expected to move $\sqrt{D}$ in $\Omega(D)$ time

Can't be improved without global localization!

Discovery Dominated



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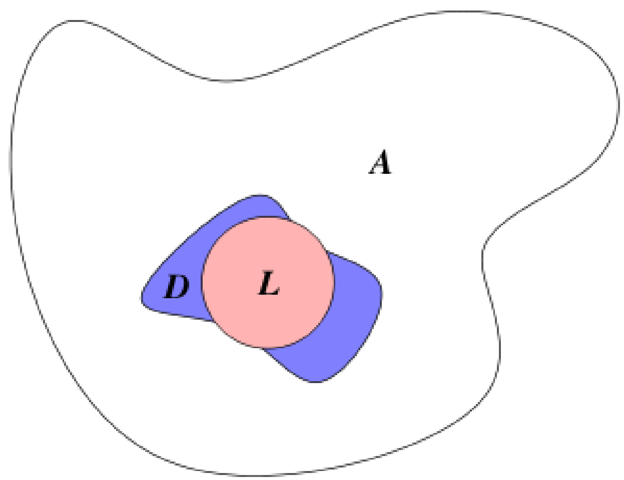
```

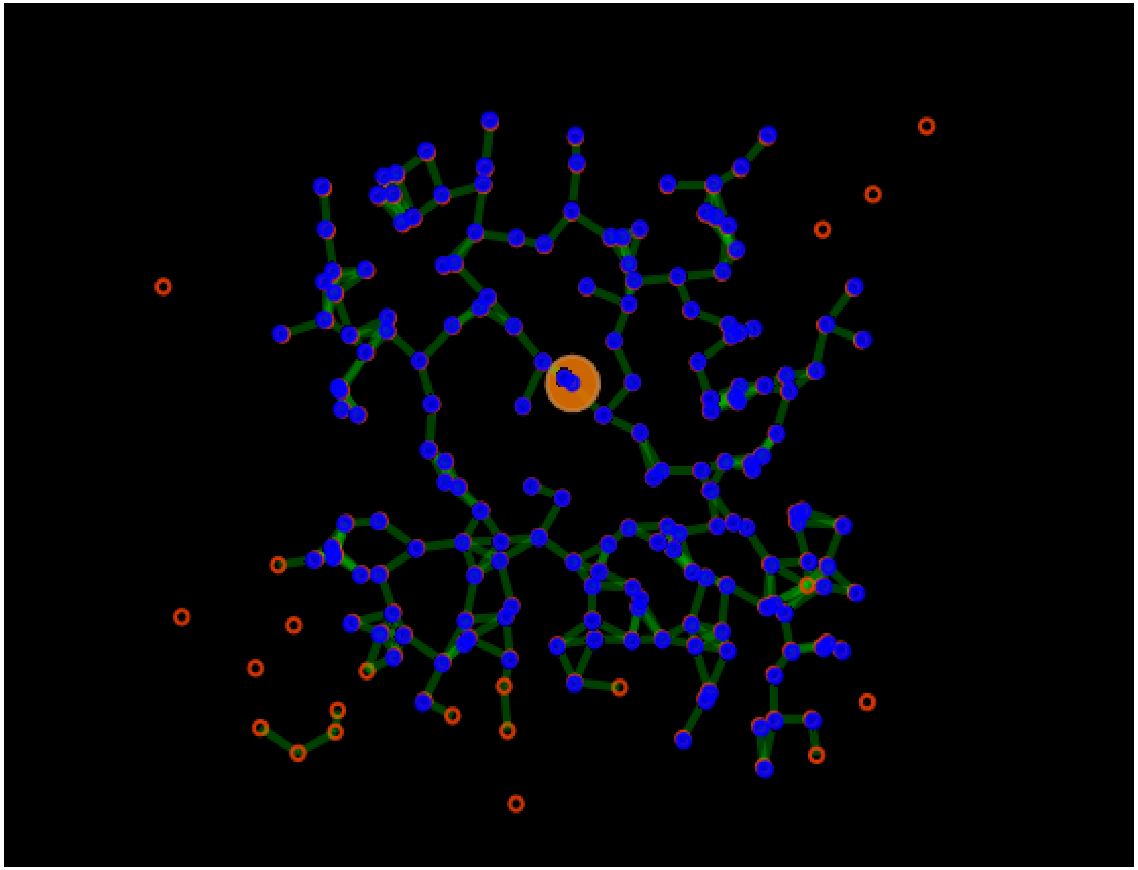
Fast Convergence

When initial and final distributions are similar, the robots seem to "crystallize":



Minimum time for message to move seed to edge: $\Theta(\sqrt{n})$

Fast Convergence



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```
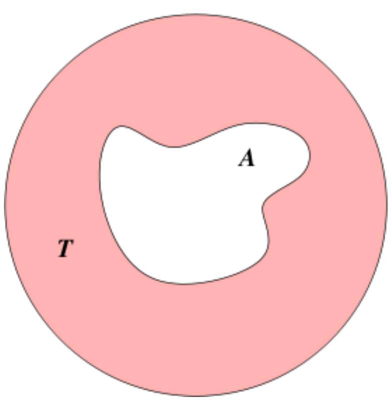
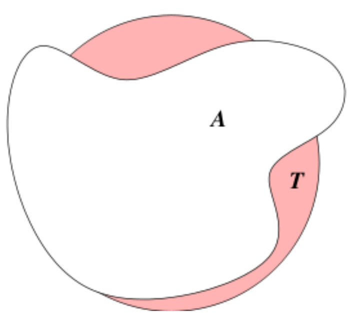

Results

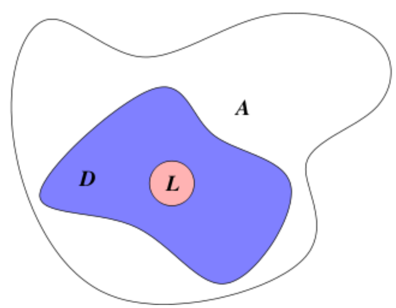
Name	Condition	Convergence	Dominant Phenomenon
Impossible	$A<T$	Impossible	Density too high
Critical	$A\approx T$	Arbitarily Long	Unlikely perfect arrangement
Discovery	$A>>D>>L$	$\Omega(D)$	Difficulty in finding seed
Fast Aggregation	$A>>D\approx[T,L]$	$\Theta(\sqrt{n})$	“Crystallization” from seed (unproved)
Dispersion	$A>>T>>D$	$\Omega(n)$	Diffusion from initial distribution



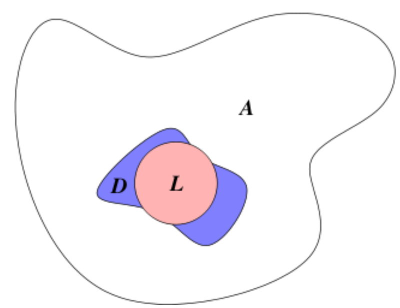
Impossible



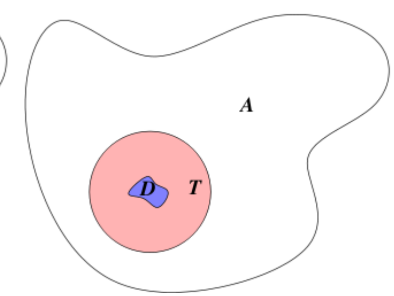
Critical



Discovery



Fast Aggregation



Dispersion

Contributions

- Five qualitative domains of behavior
- Random navigation is not sufficient
- Some long-range coordination is necessary