Scheduling Parallel Programs by Work Stealing with Private Deques

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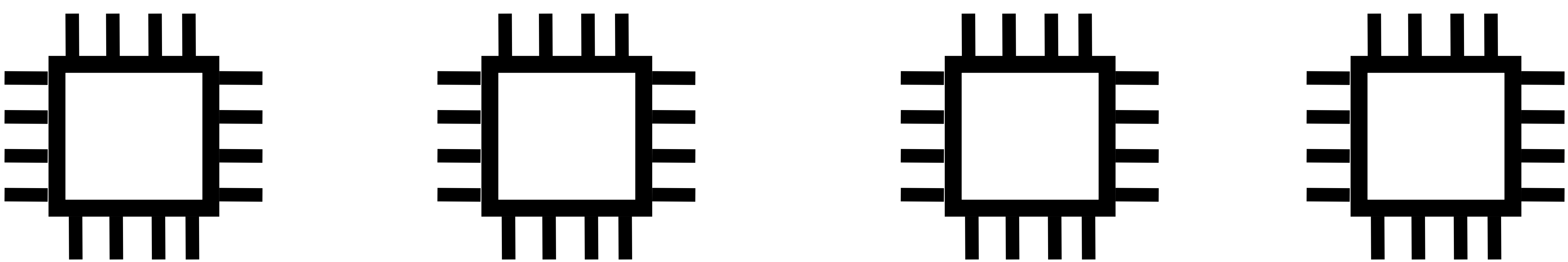
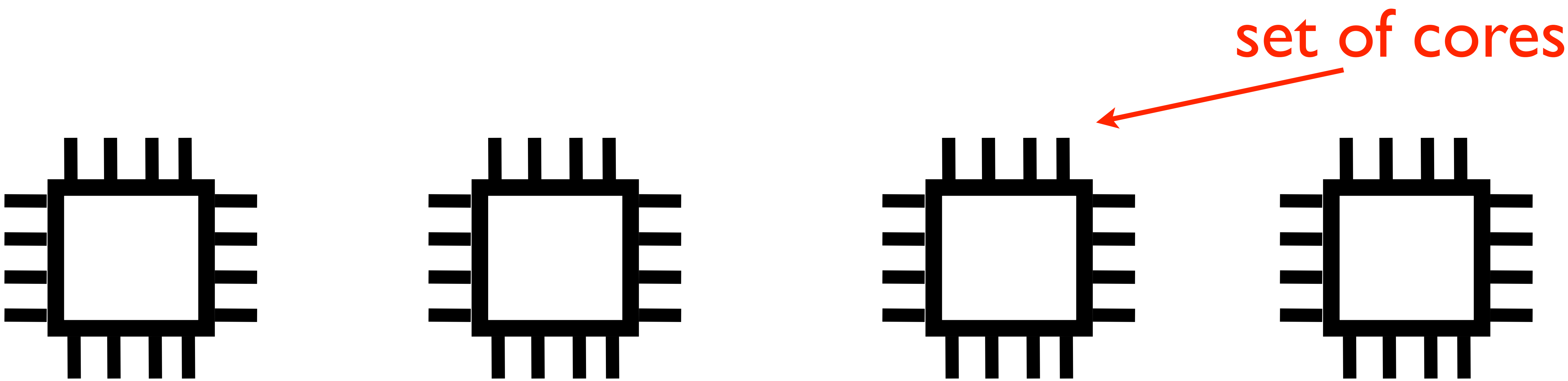
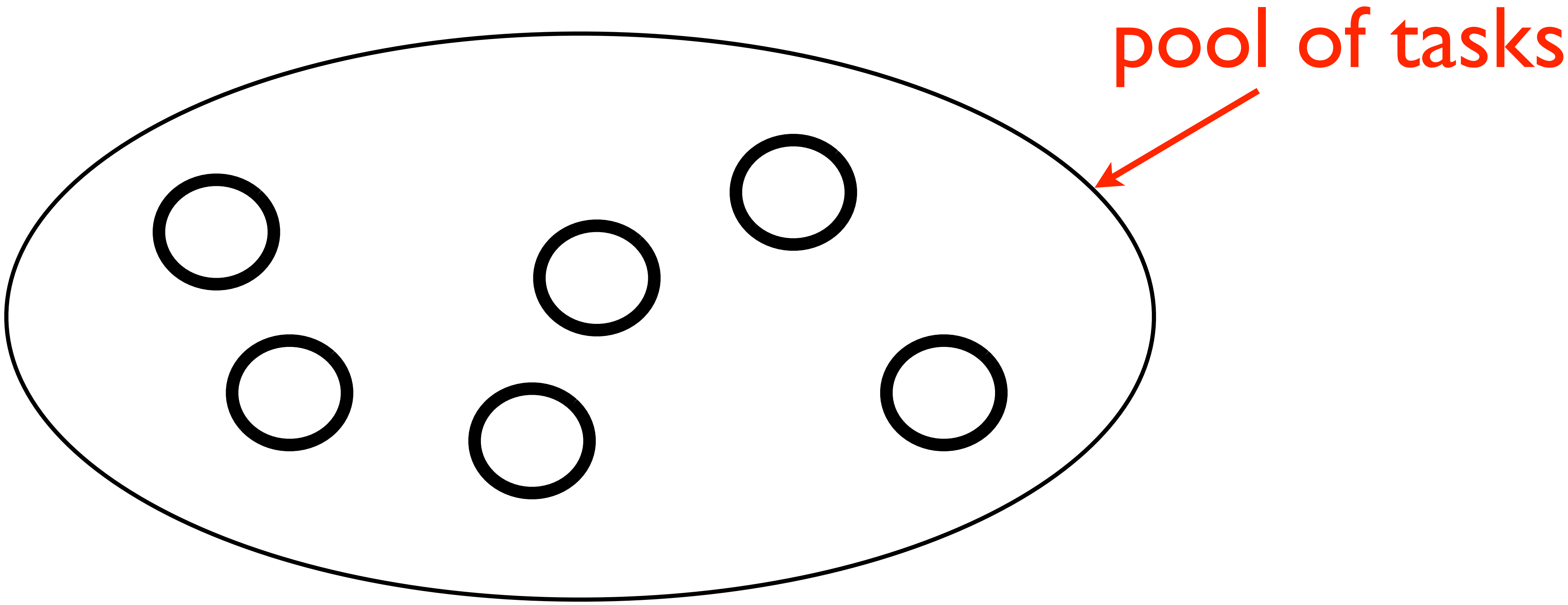
Scheduling parallel tasks

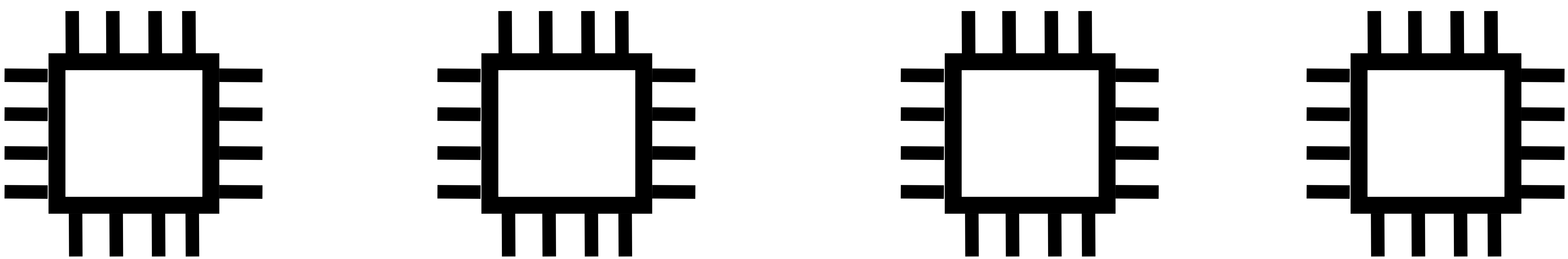


Scheduling parallel tasks



Scheduling parallel tasks

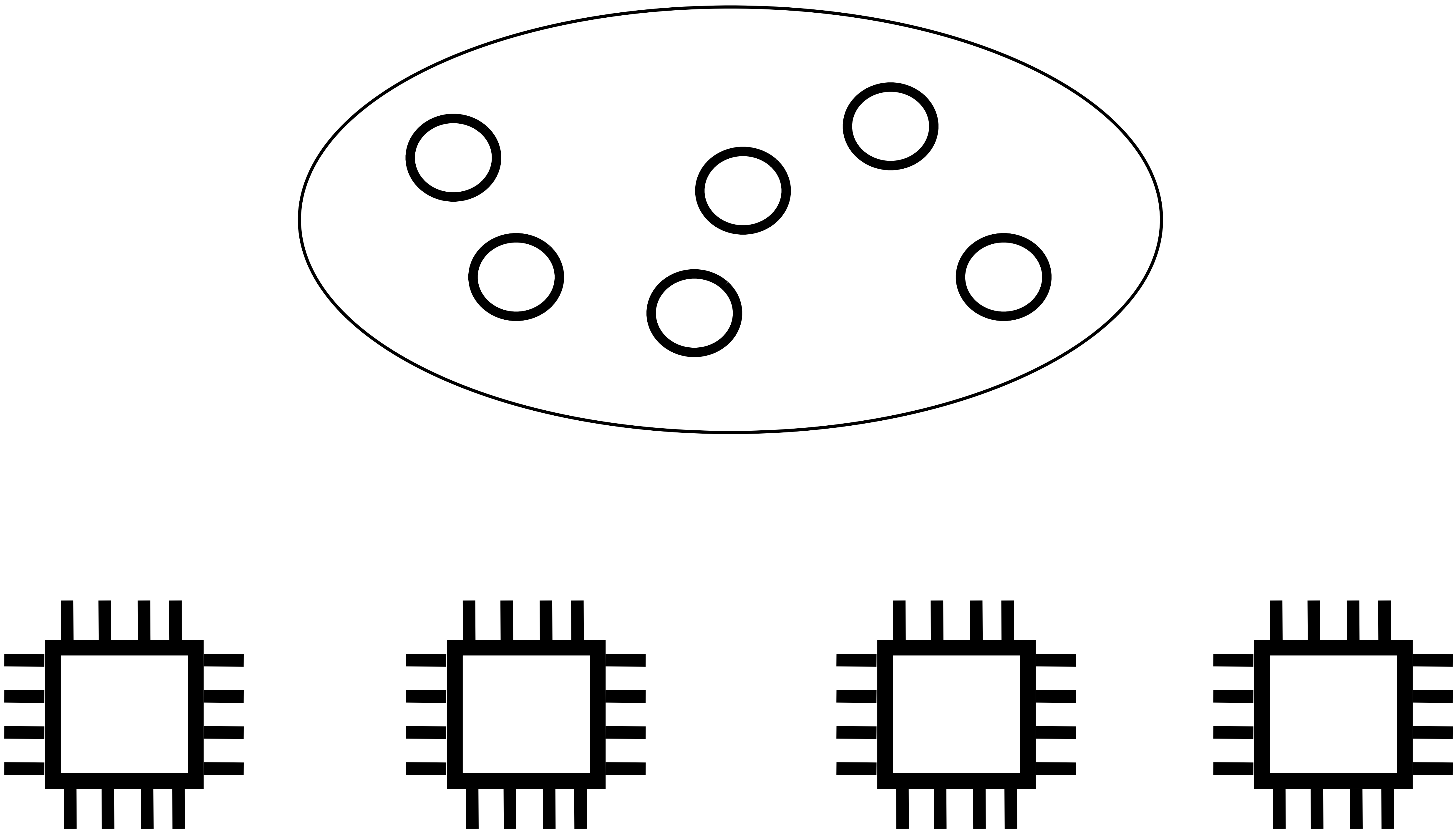




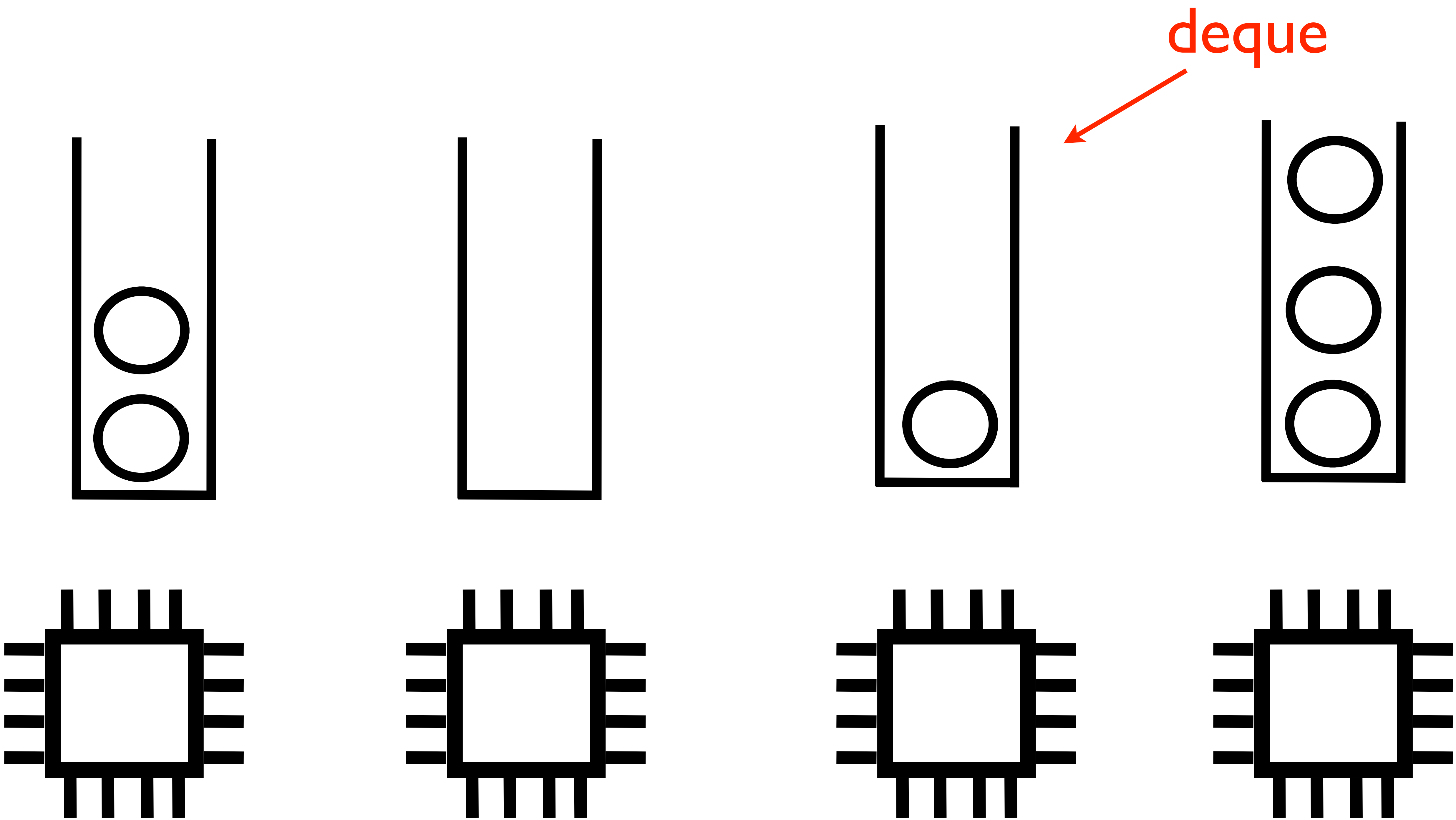
Scheduling parallel tasks

- Goal: dynamic load balancing
- A centralized approach: does not scale up
- Popular approach: work stealing
- Our work: study implementations of work stealing

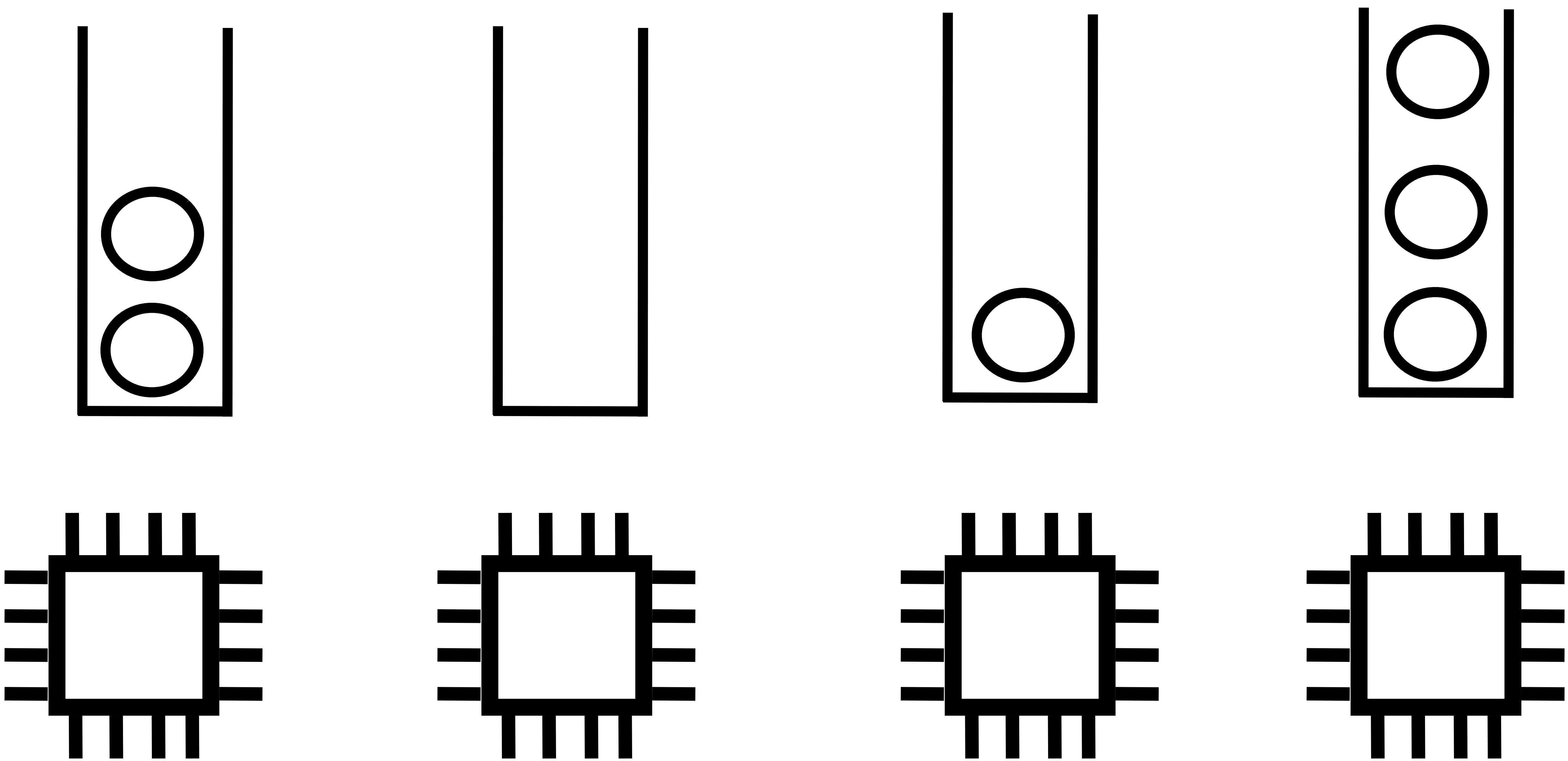
Work stealing



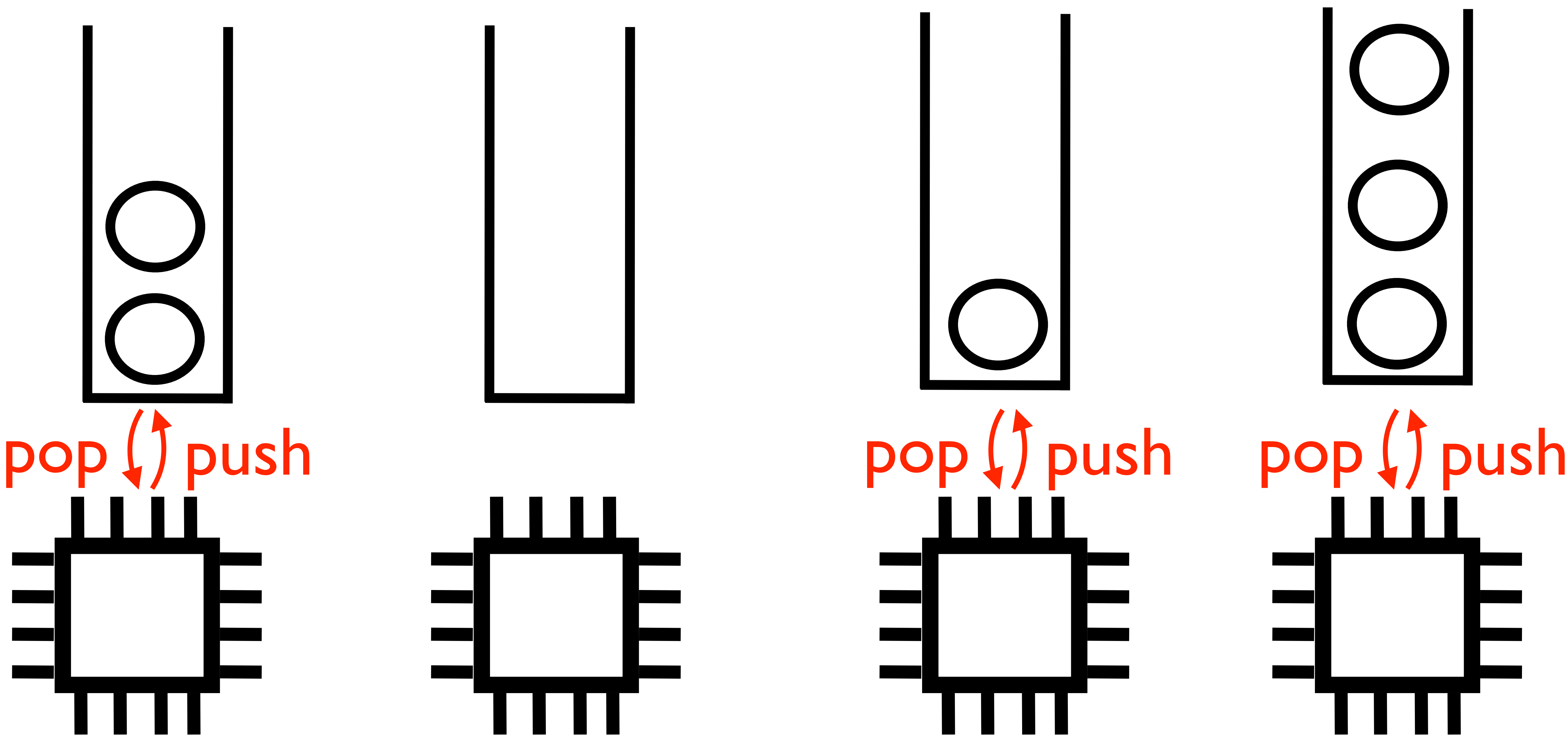
Work stealing



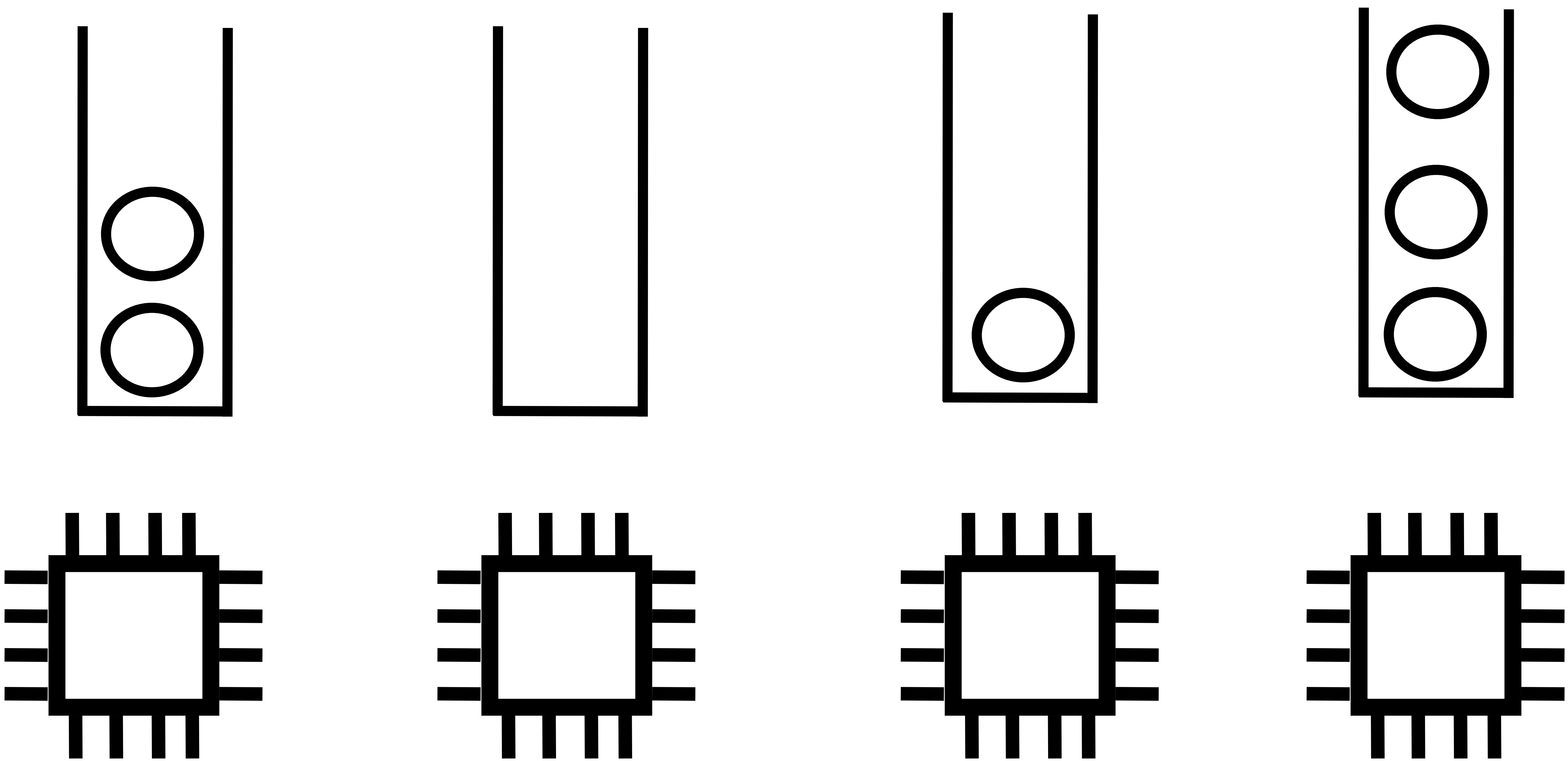
Work stealing



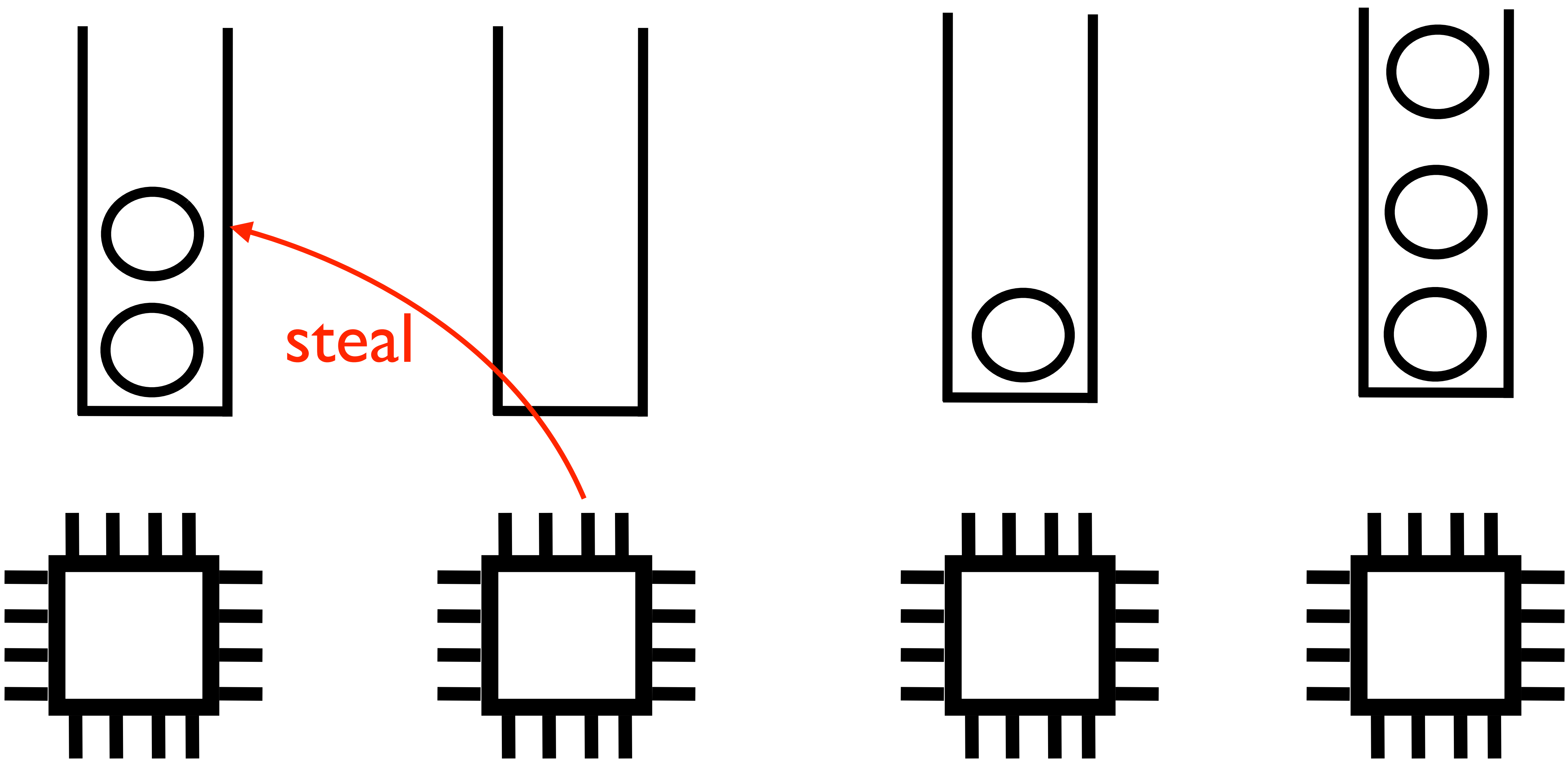
Work stealing



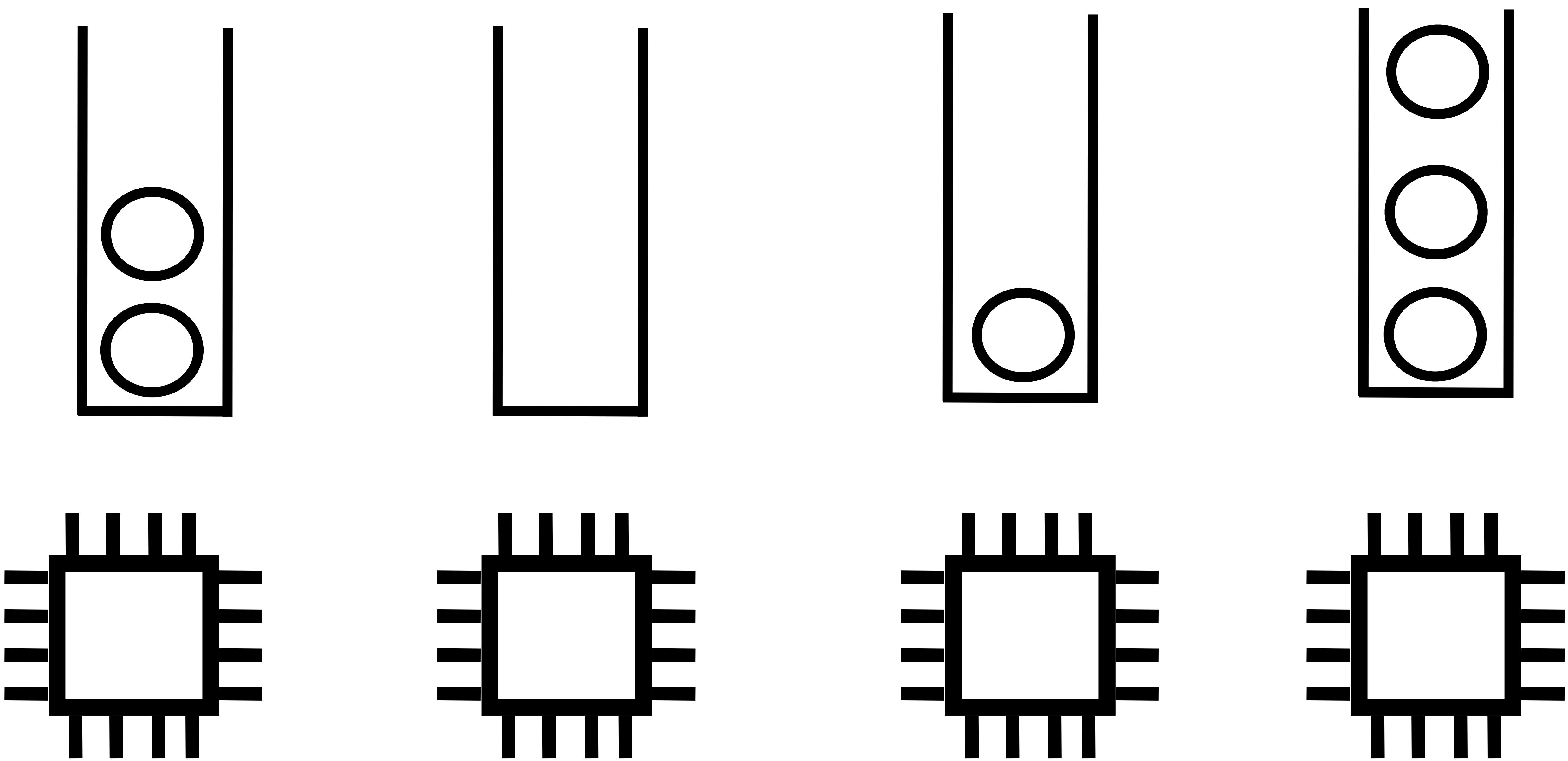
Work stealing



Work stealing

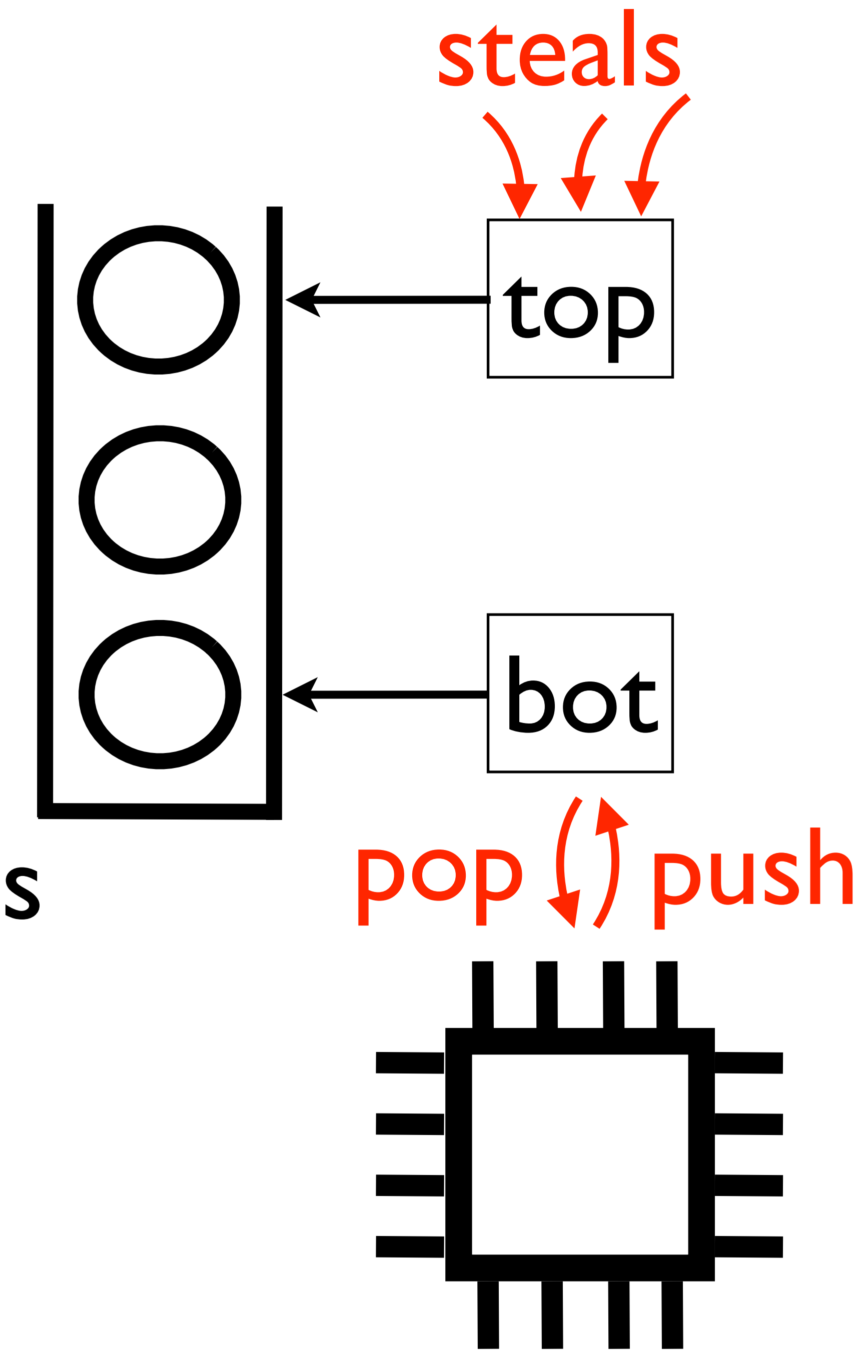


Work stealing



Concurrent deques

- Deques are shared.
- Two sources of race:
  - between thieves
  - between owner and thief
- Chase-Lev data structure resolves these races using atomic compare&swap and memory fences.



Concurrent deques

- **Well studied:** shown to perform well both in theory and in practice ...

however, researchers identified two main limitations

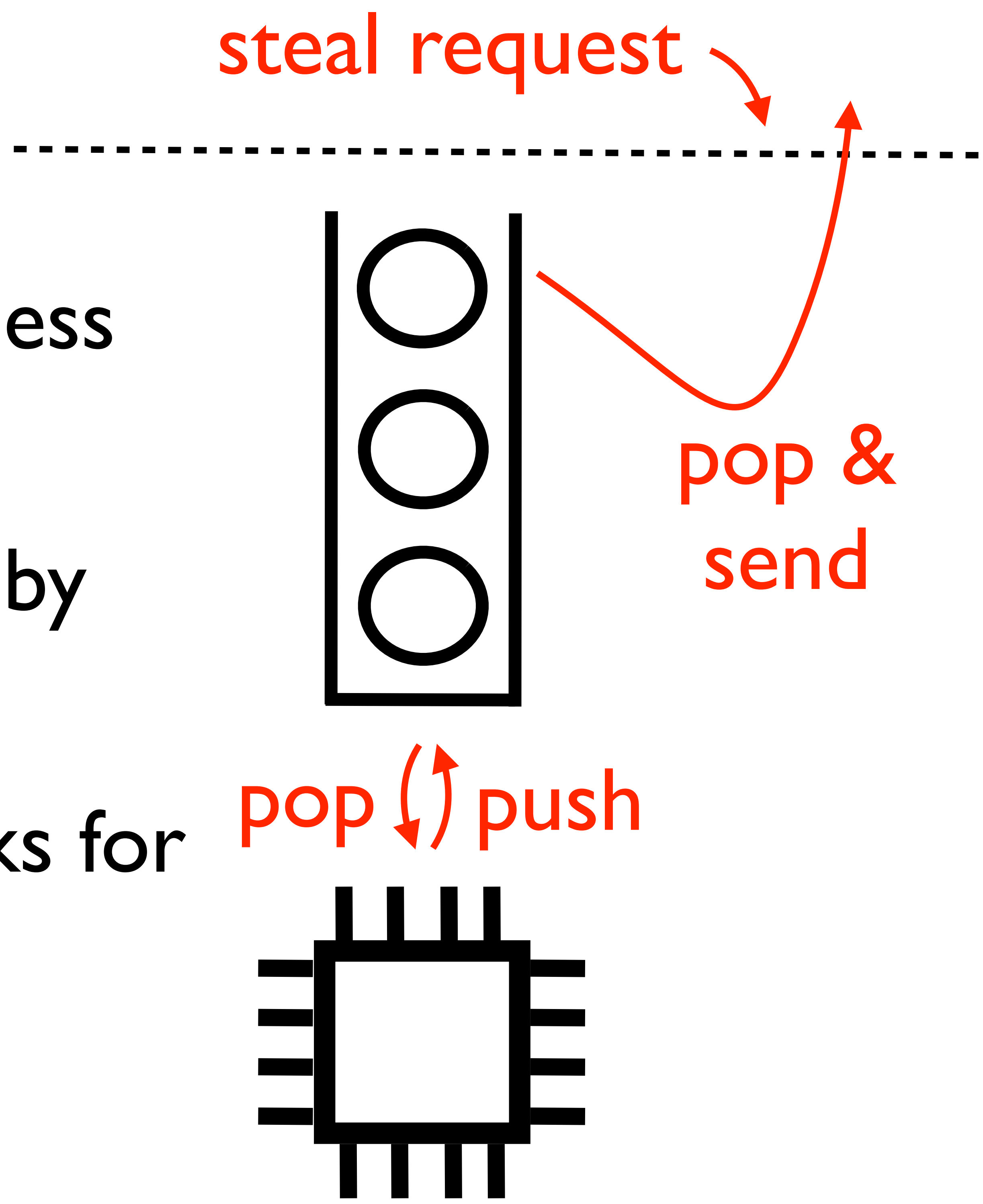
- **Runtime overhead:** In a relaxed memory model, `pop` must use a memory fence.
- **Lack of flexibility:** Simple extensions (e.g., steal half) involve major challenges.

Previous studies of private deques

Feeley	1992	Multilisp
Hendler & Shavit	2002	C
Umatani	2003	Java
Hirashi et al.	2009	C
Sanchez et al.	2010	C
Fluet et al.	2011	Parallel ML

Private deques

- Each core has exclusive access to its own deque.
- An idle core obtains a task by making a *steal request.*
- A busy core regularly checks for incoming requests.



Private deques

Addresses the main limitations of concurrent deques:

- no need for memory fence
- flexible deques (any data structure can be used)

but

- new cost associated with regular polling
- additional delay associated with steals

Unknowns of private deques

- What is the best way to implement work stealing with private deques?
- How does it compare on state of art benchmarks with concurrent deques?
- Can establish tight bounds on the runtime?

Unknowns of private deques

- What is the best way to implement work stealing with private deques?

  We give a receiver- and a sender-initiated algorithm.

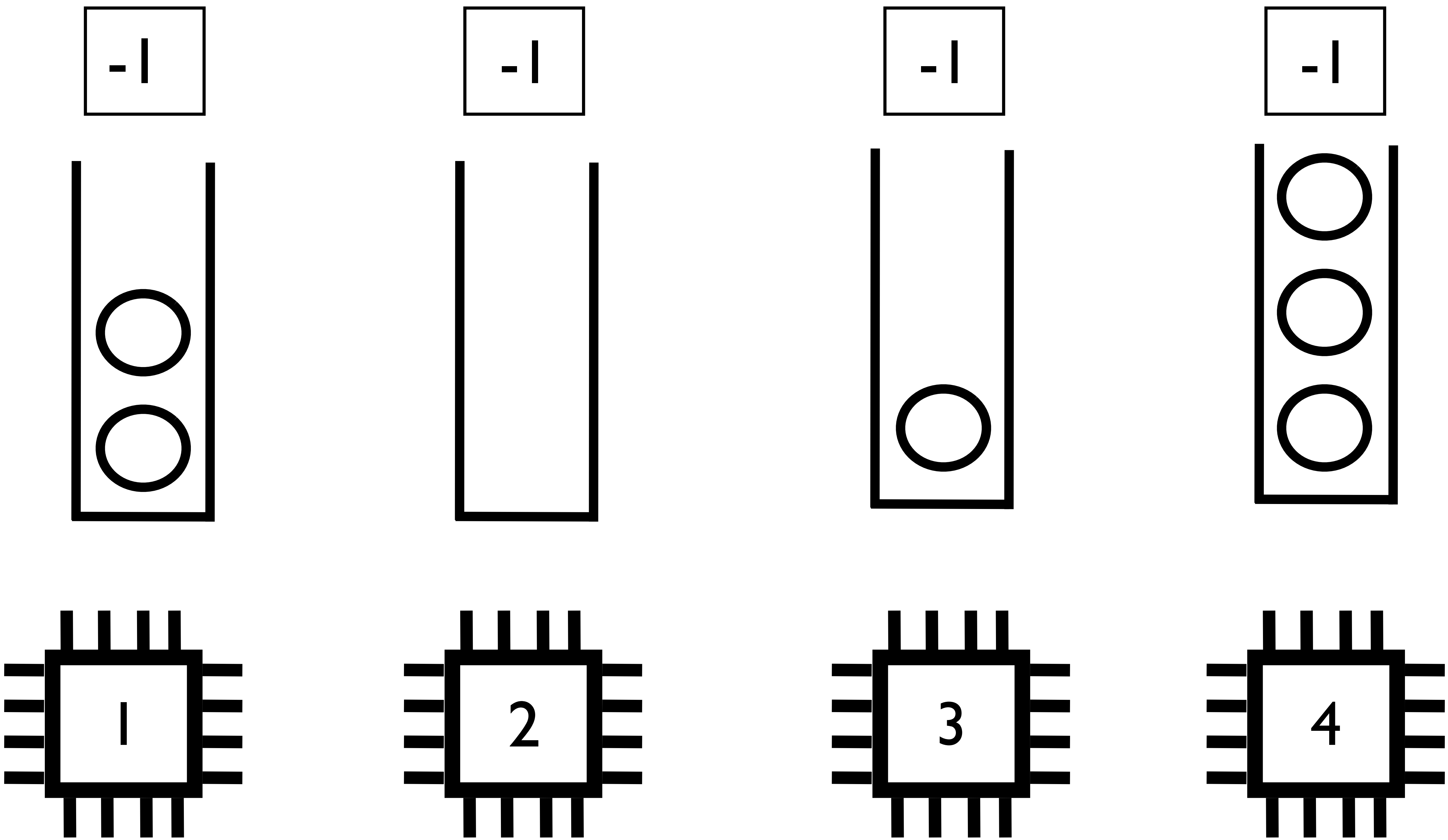
- How does it compare on state of art benchmarks with concurrent deques?

  We evaluate on a collection of benchmarks.

- Can establish tight bounds on the runtime?

  We prove a theorem w.r.t. delay and polling overhead.

Receiver initiated



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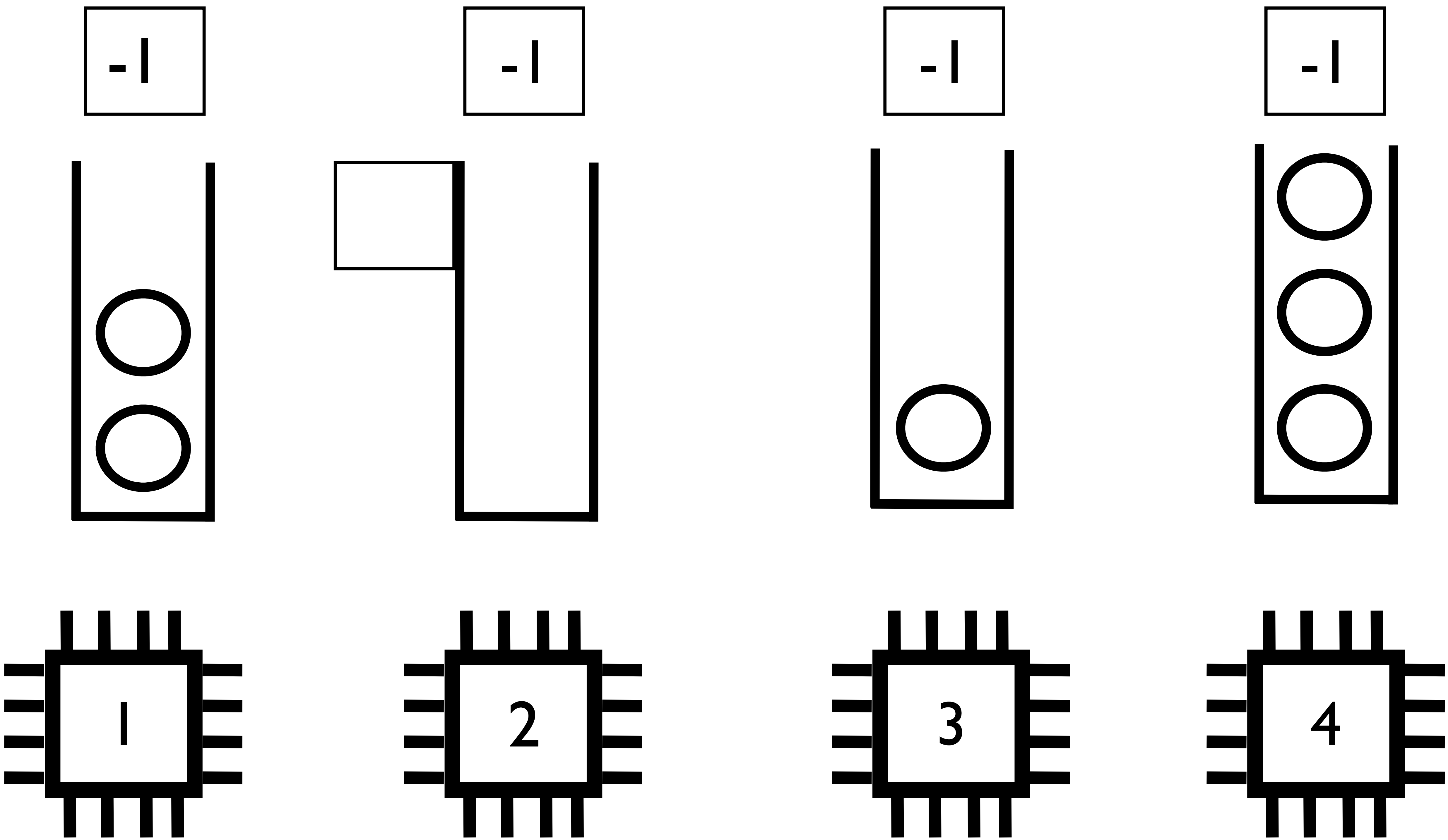
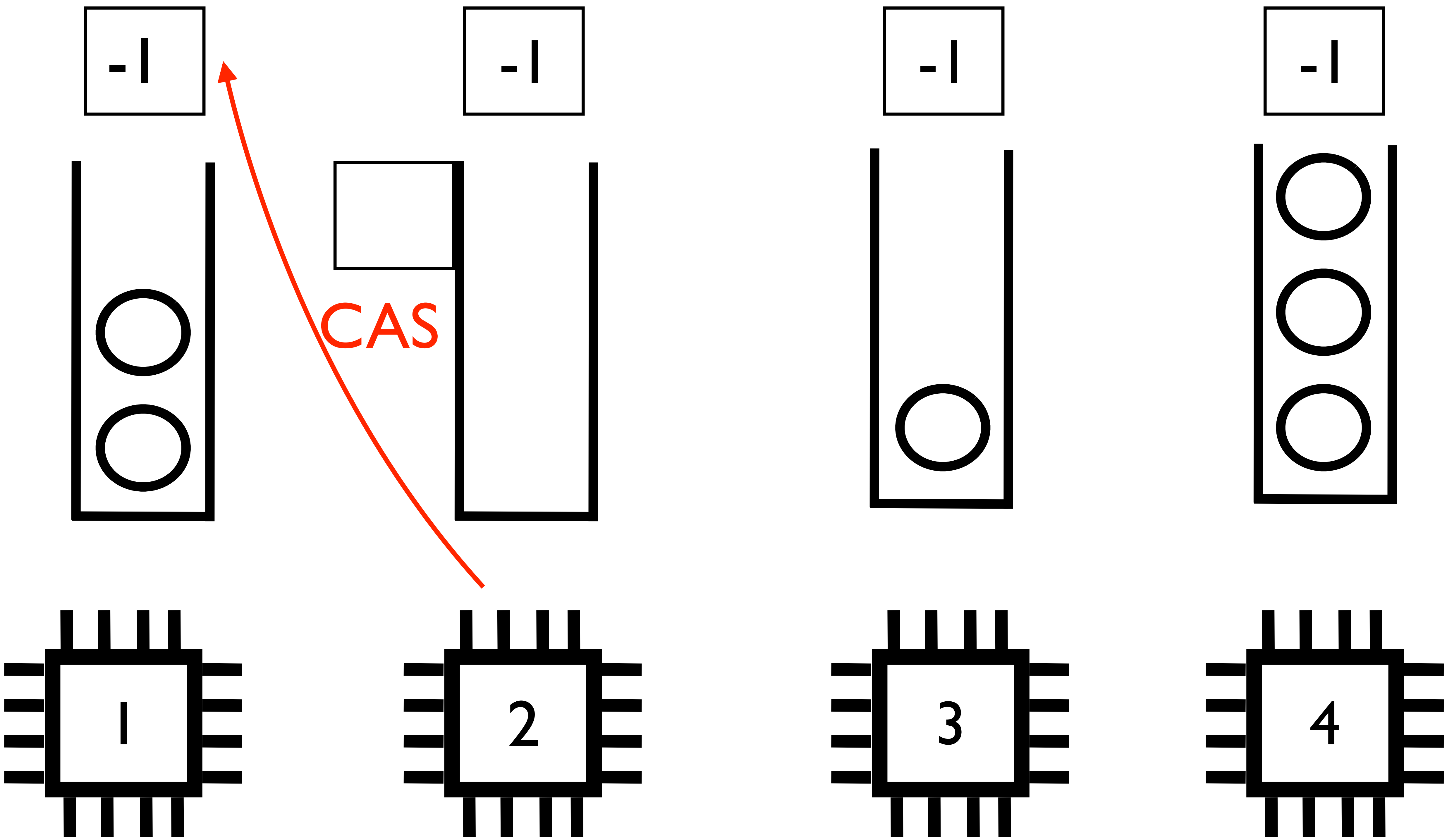


Receiver initiated



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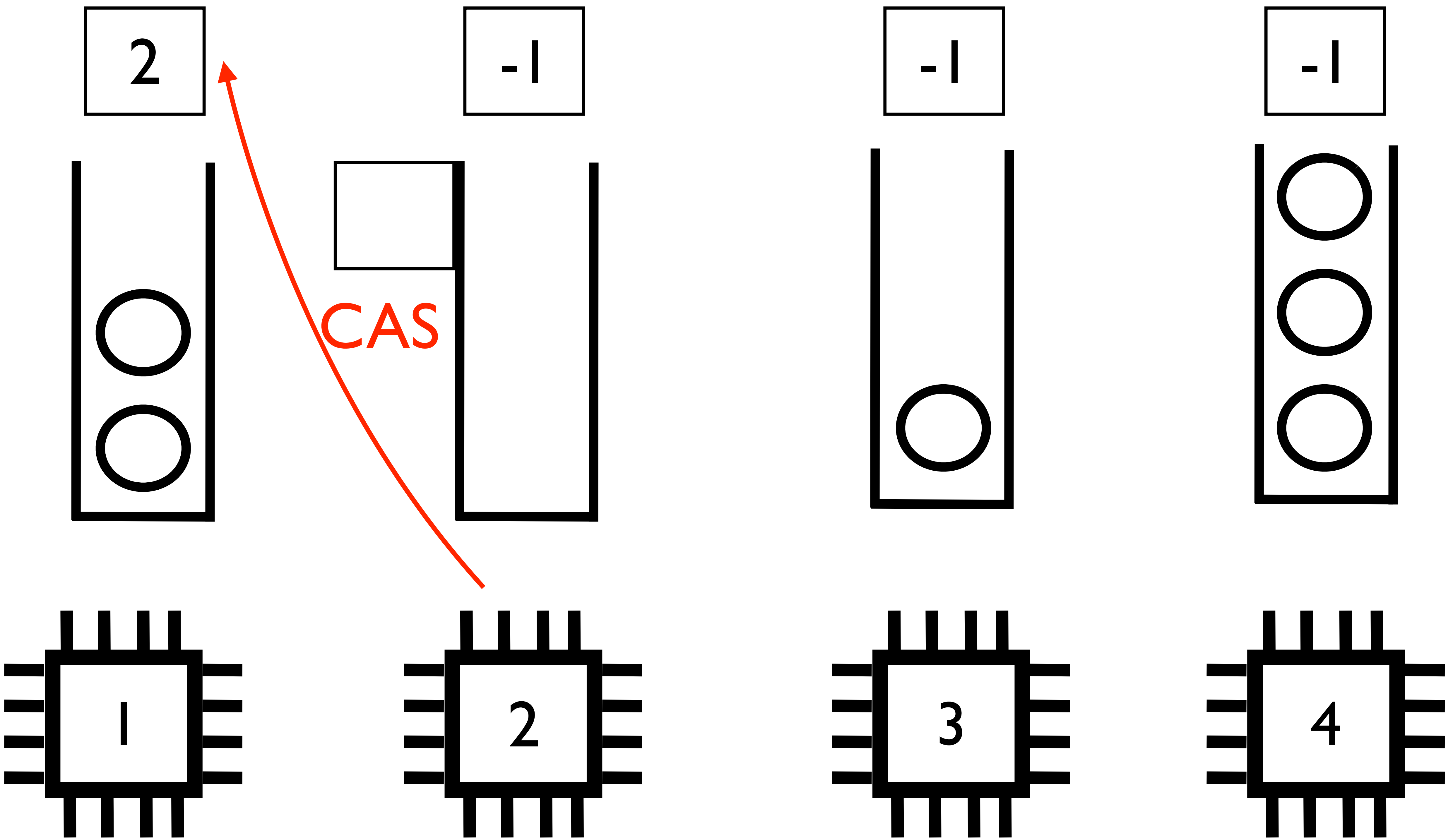

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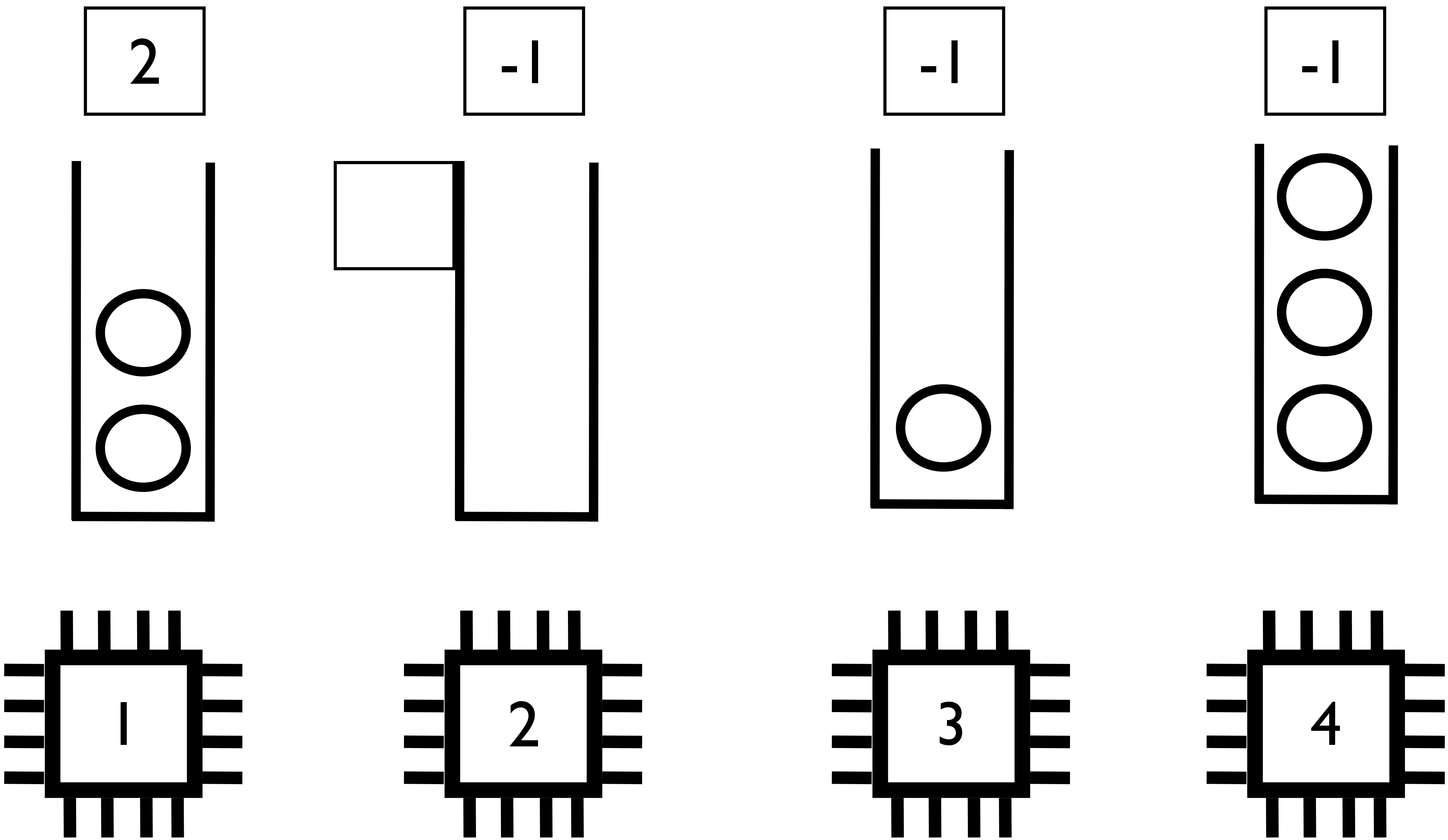

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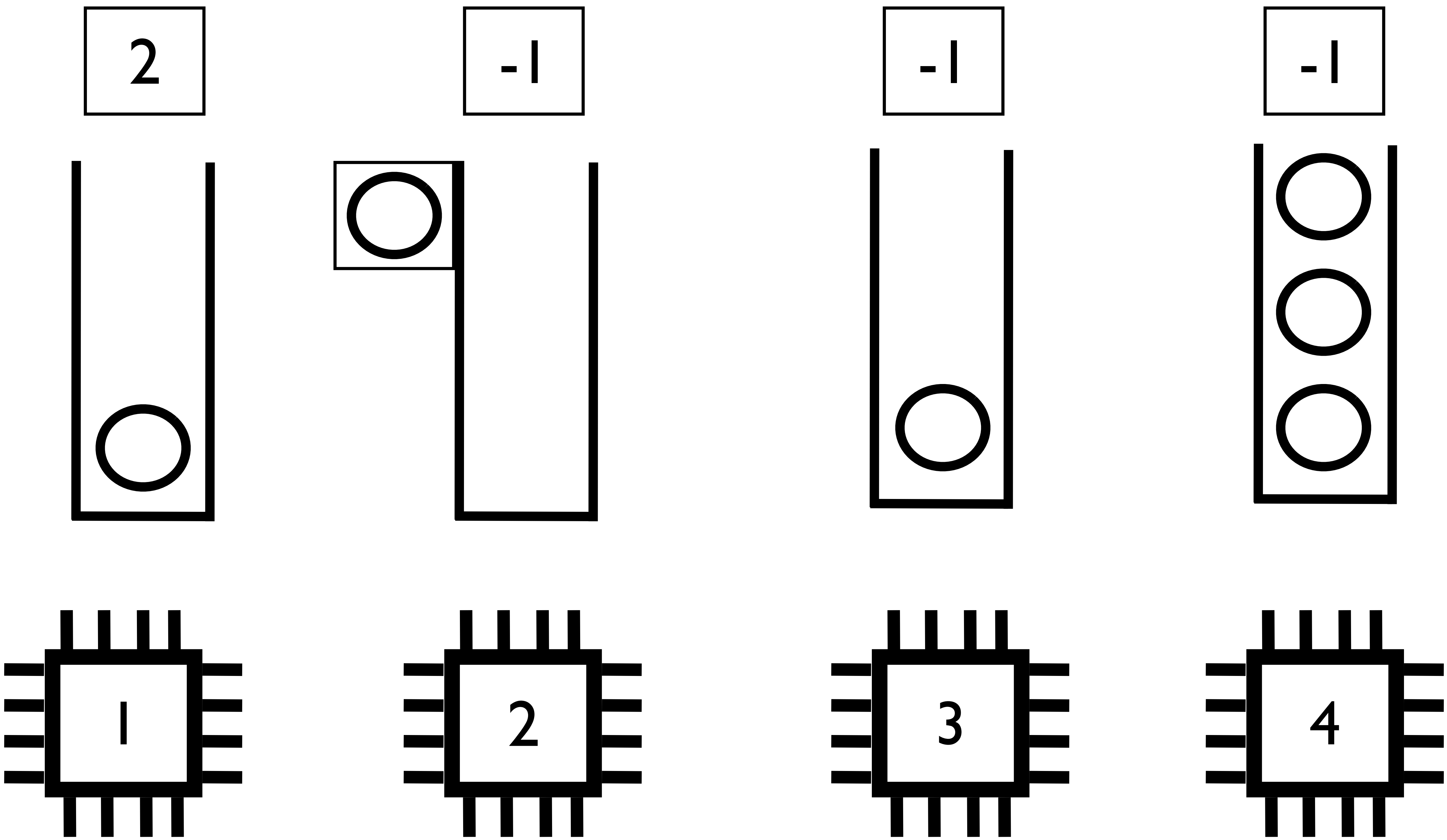

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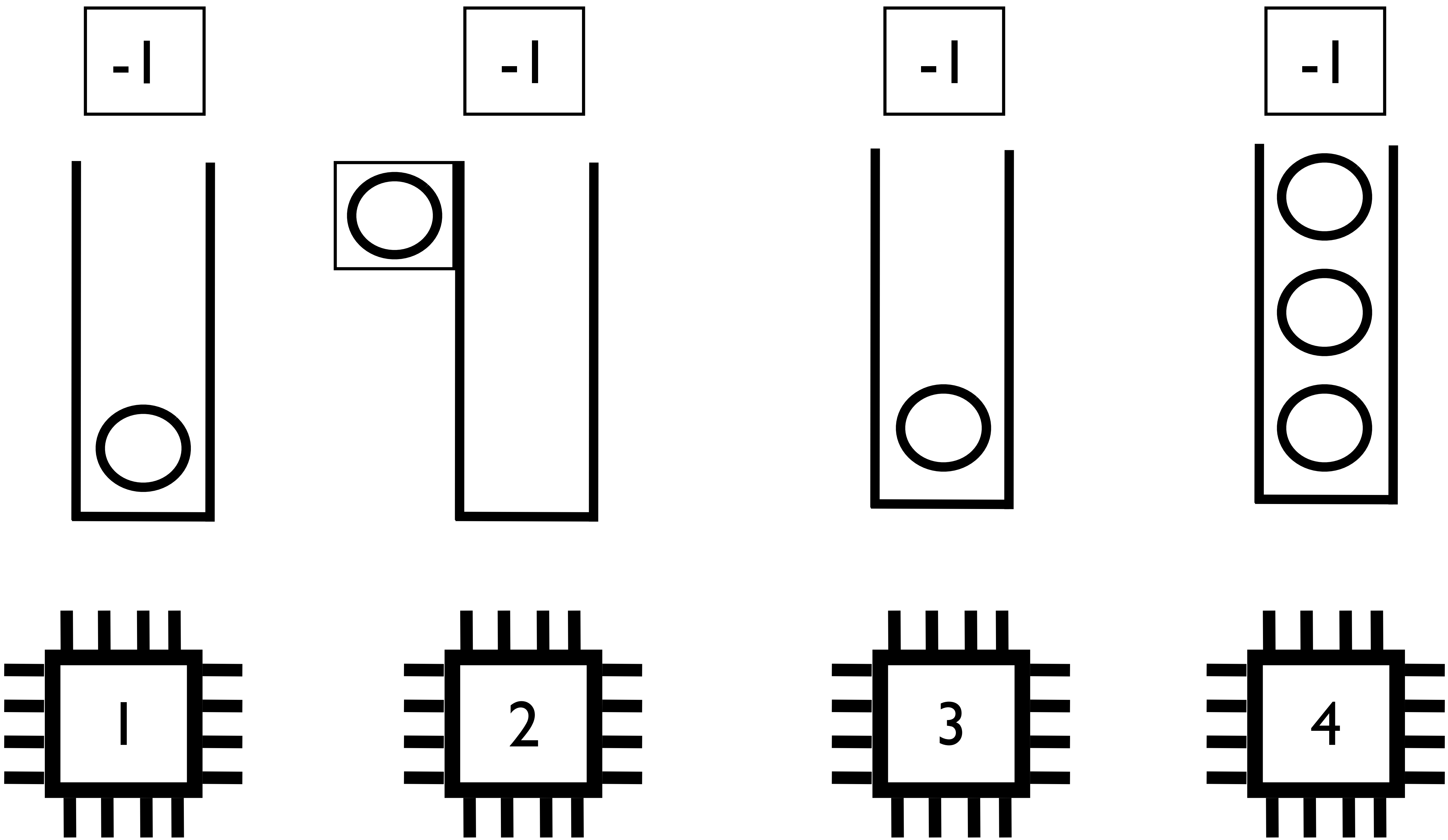

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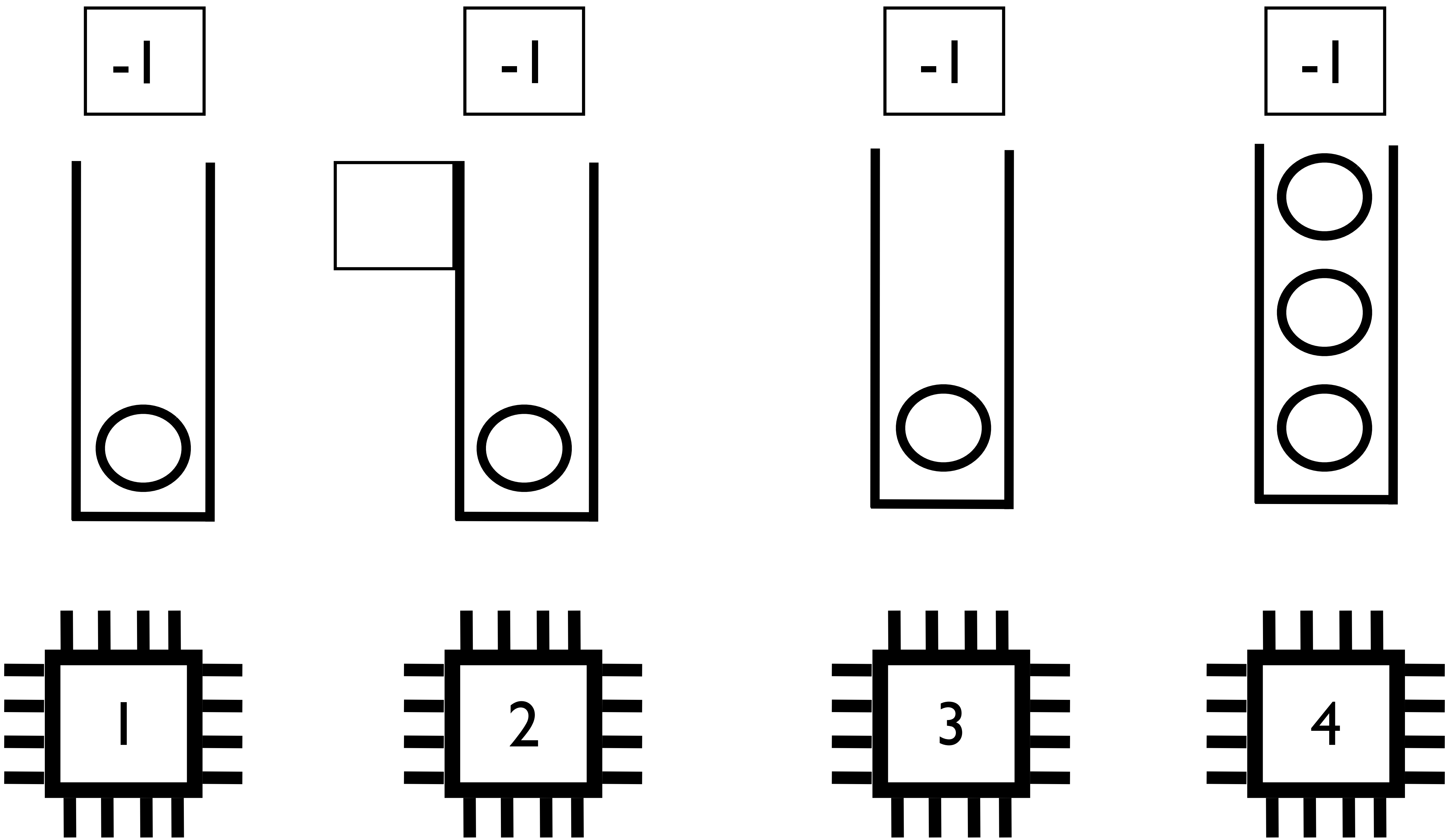
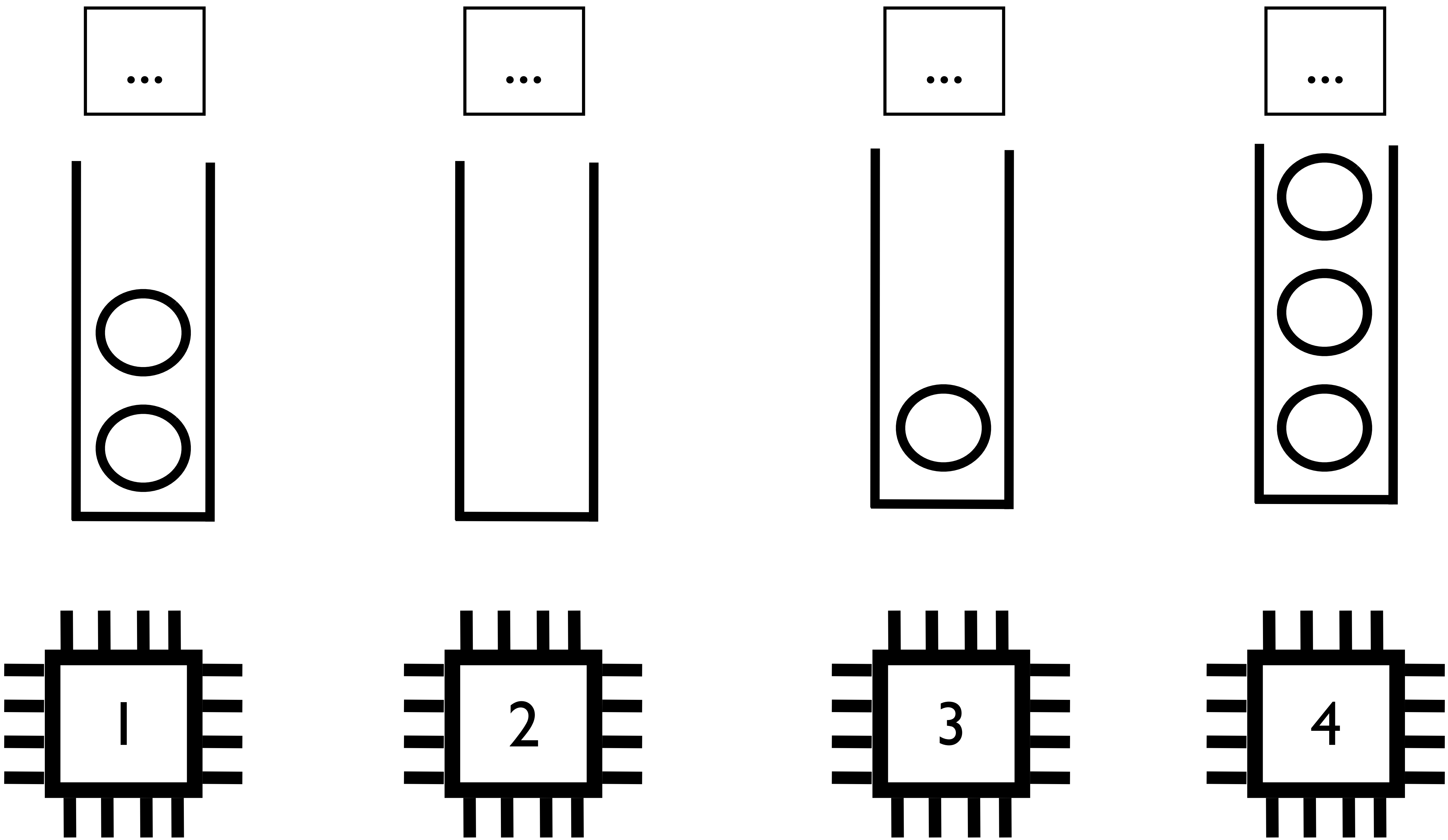


From receiver to sender initiated

- Receiver initiated: each idle core targets one busy core at random
- Sender initiated: each busy core targets one core at random
- Sender initiated idea is adapted from distributed computing.
- Sender initiated is simpler to implement.

Sender initiated



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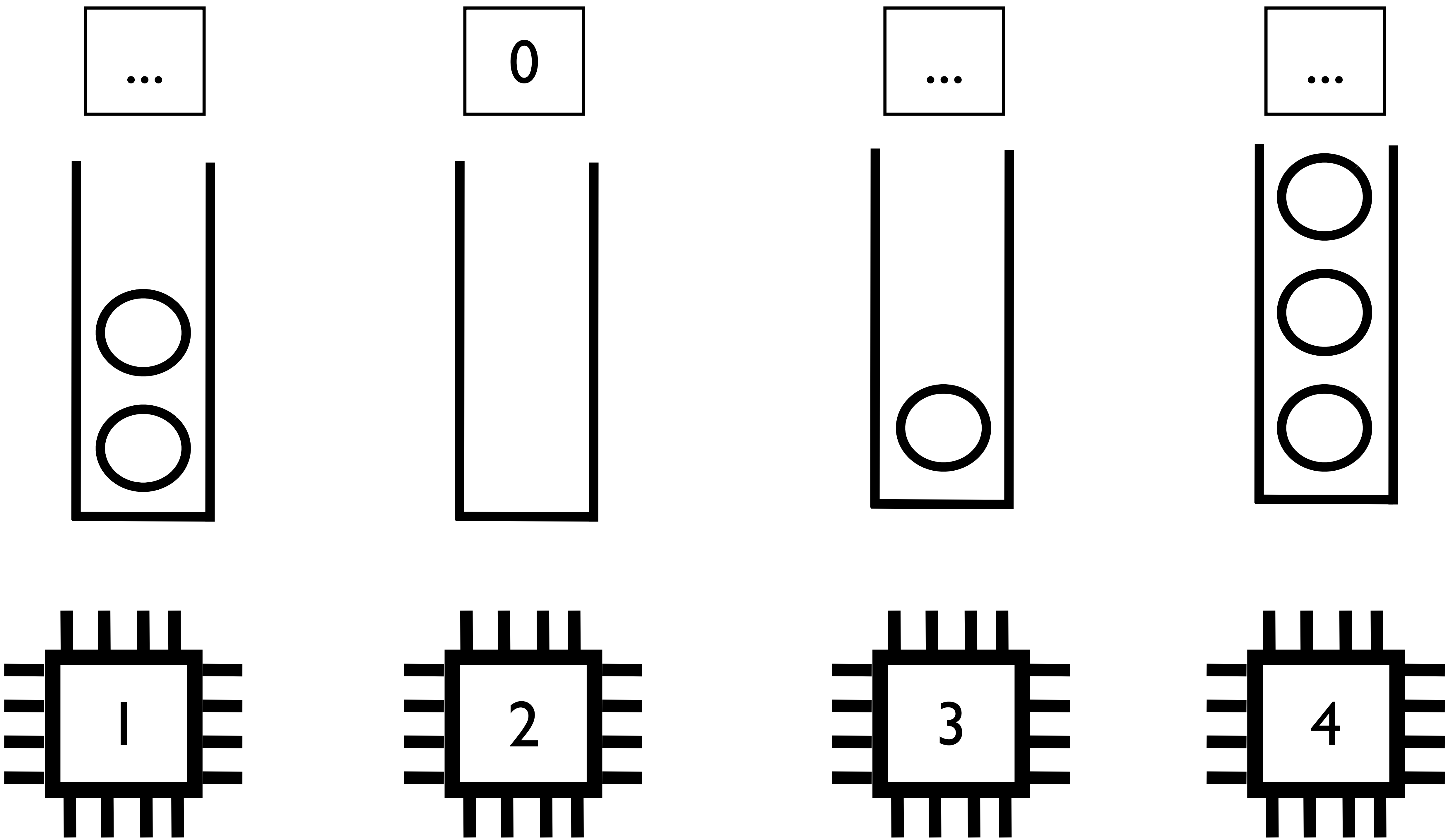

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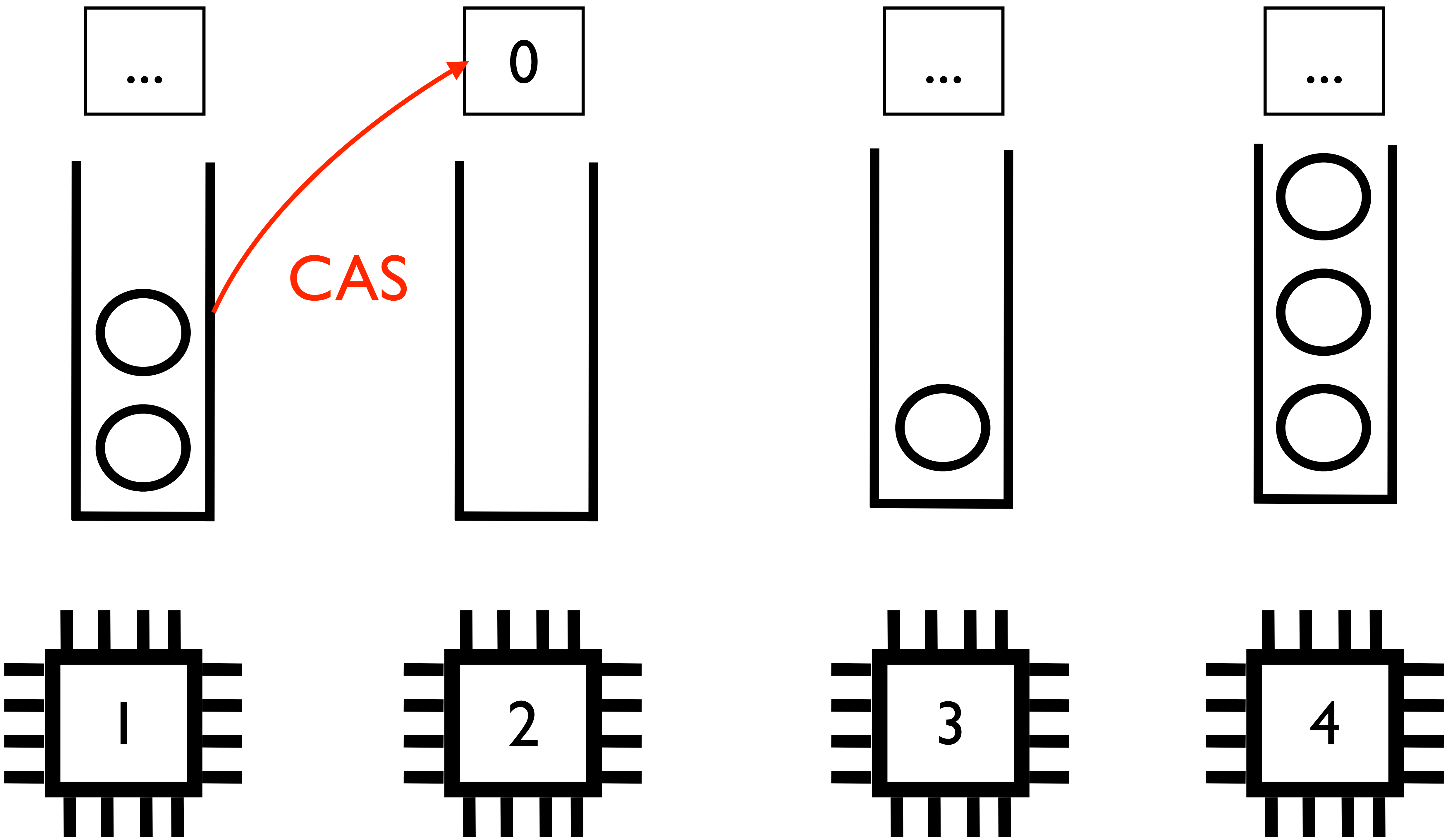

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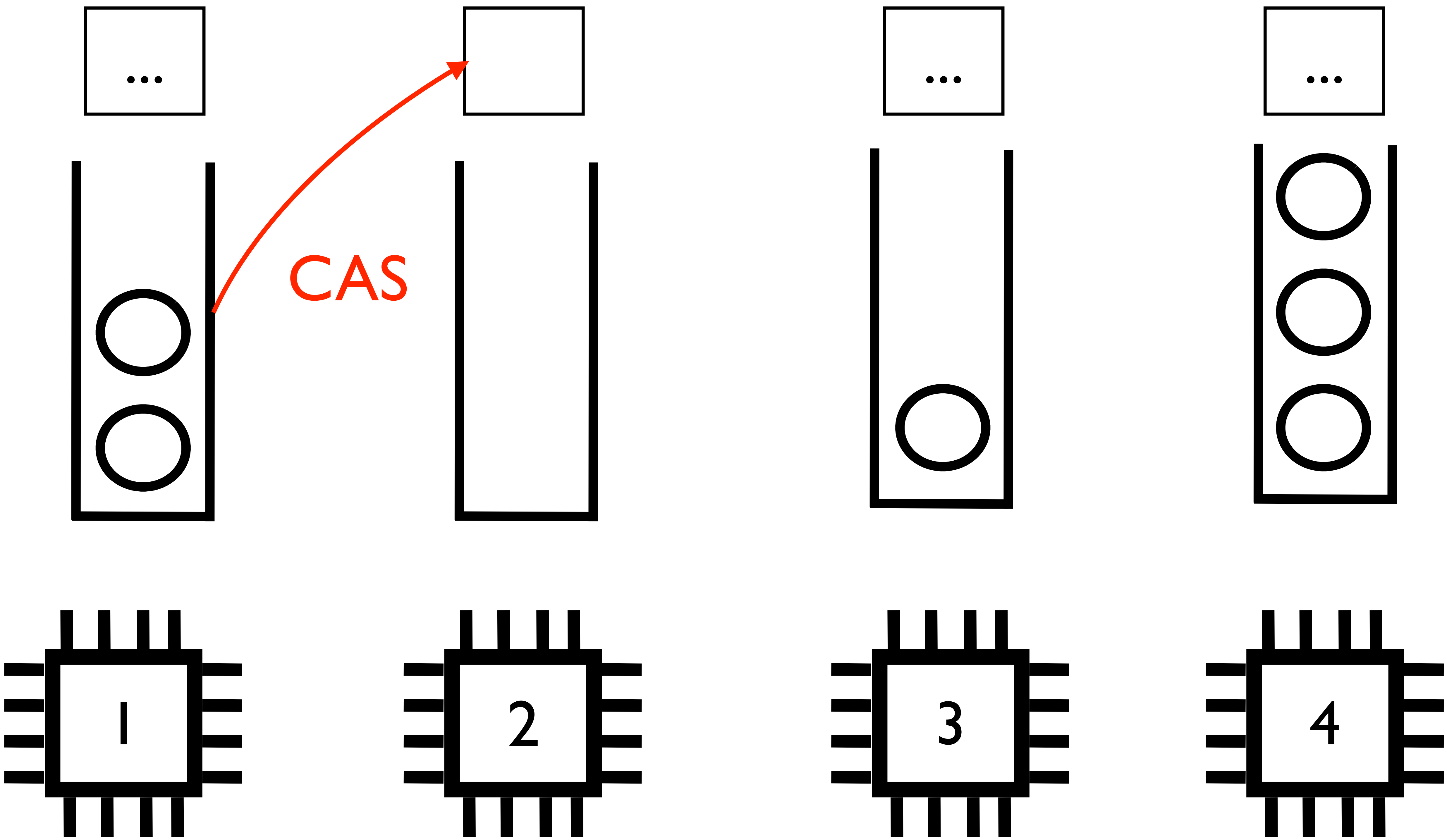

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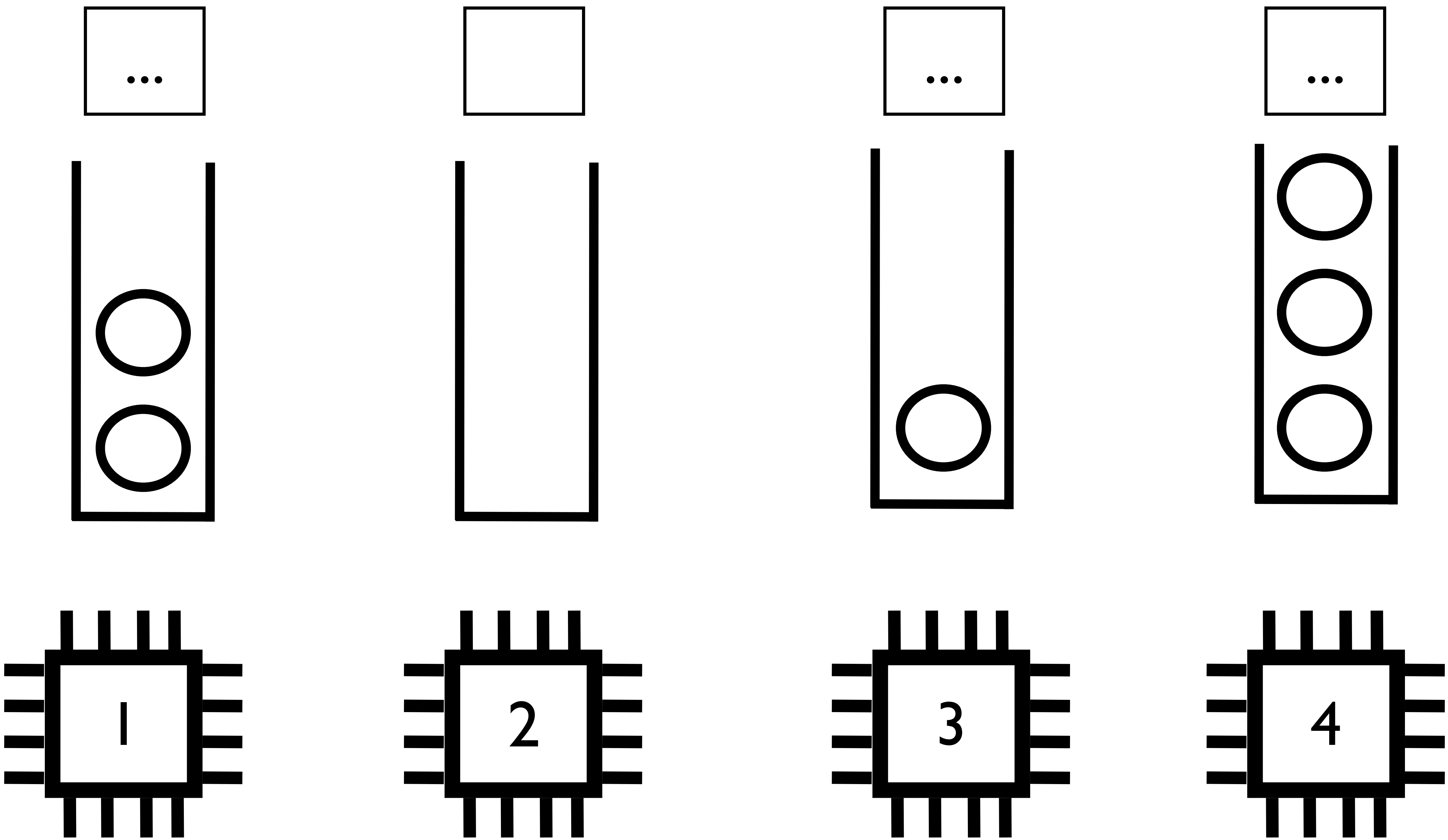

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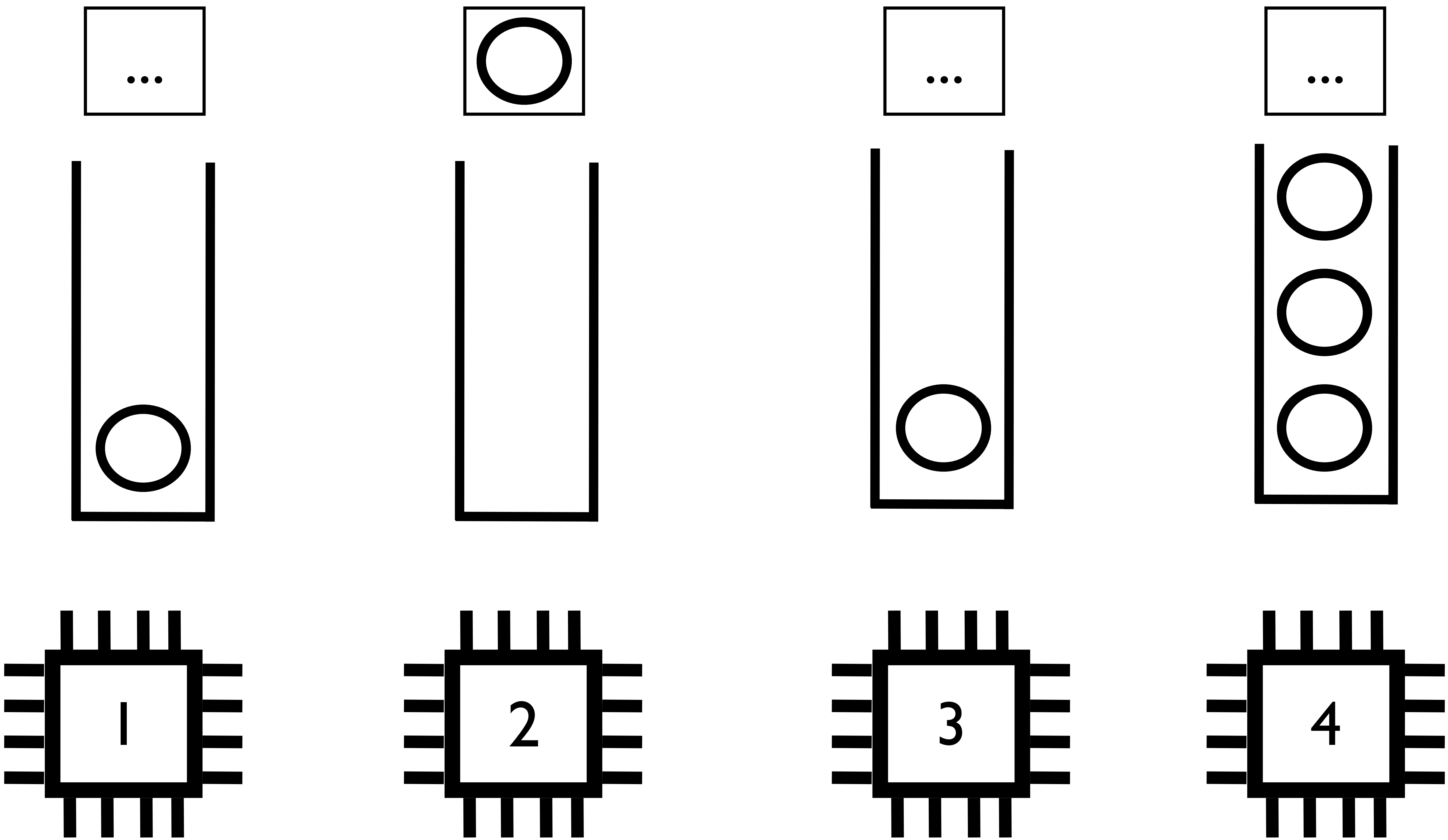

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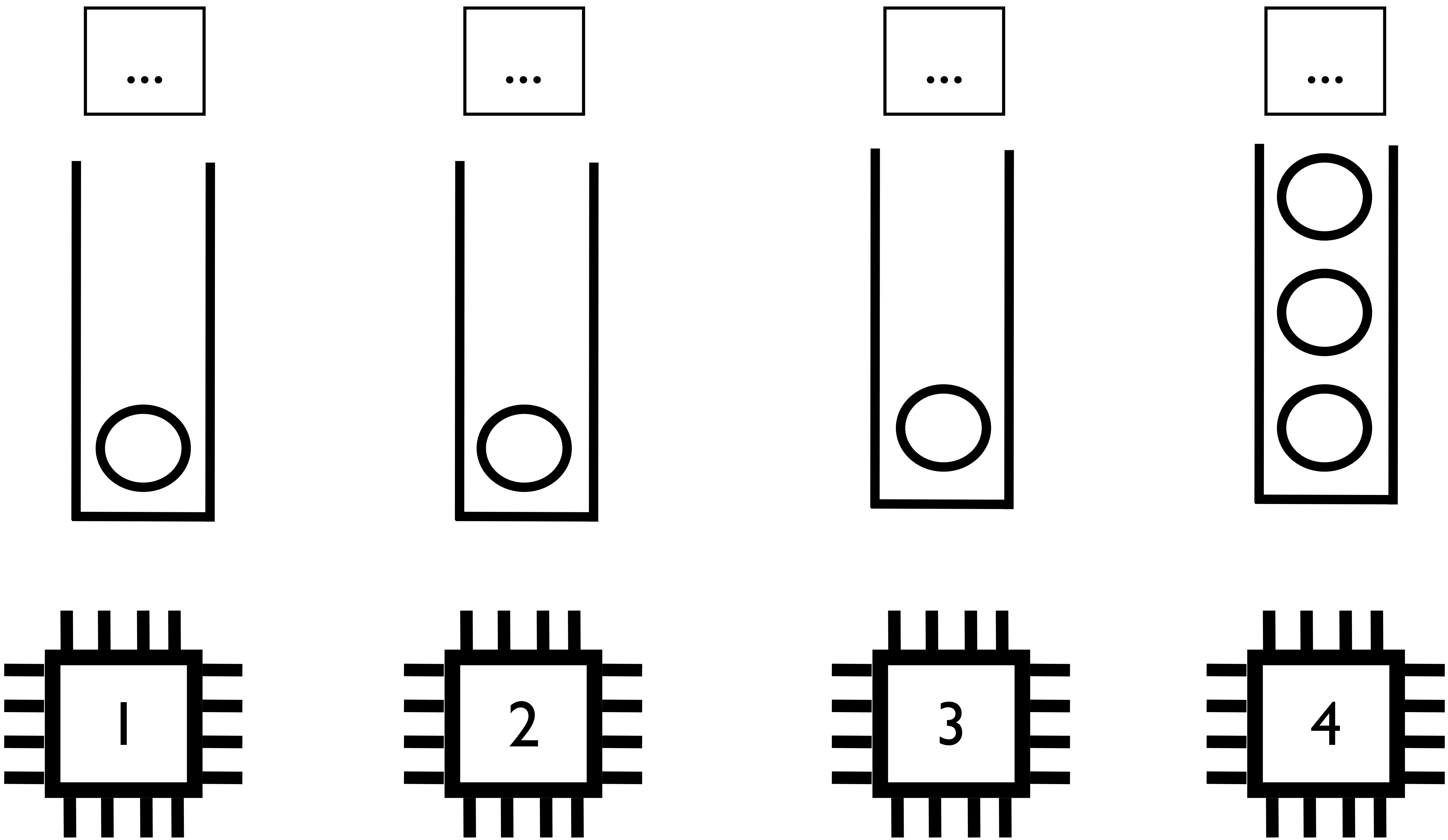


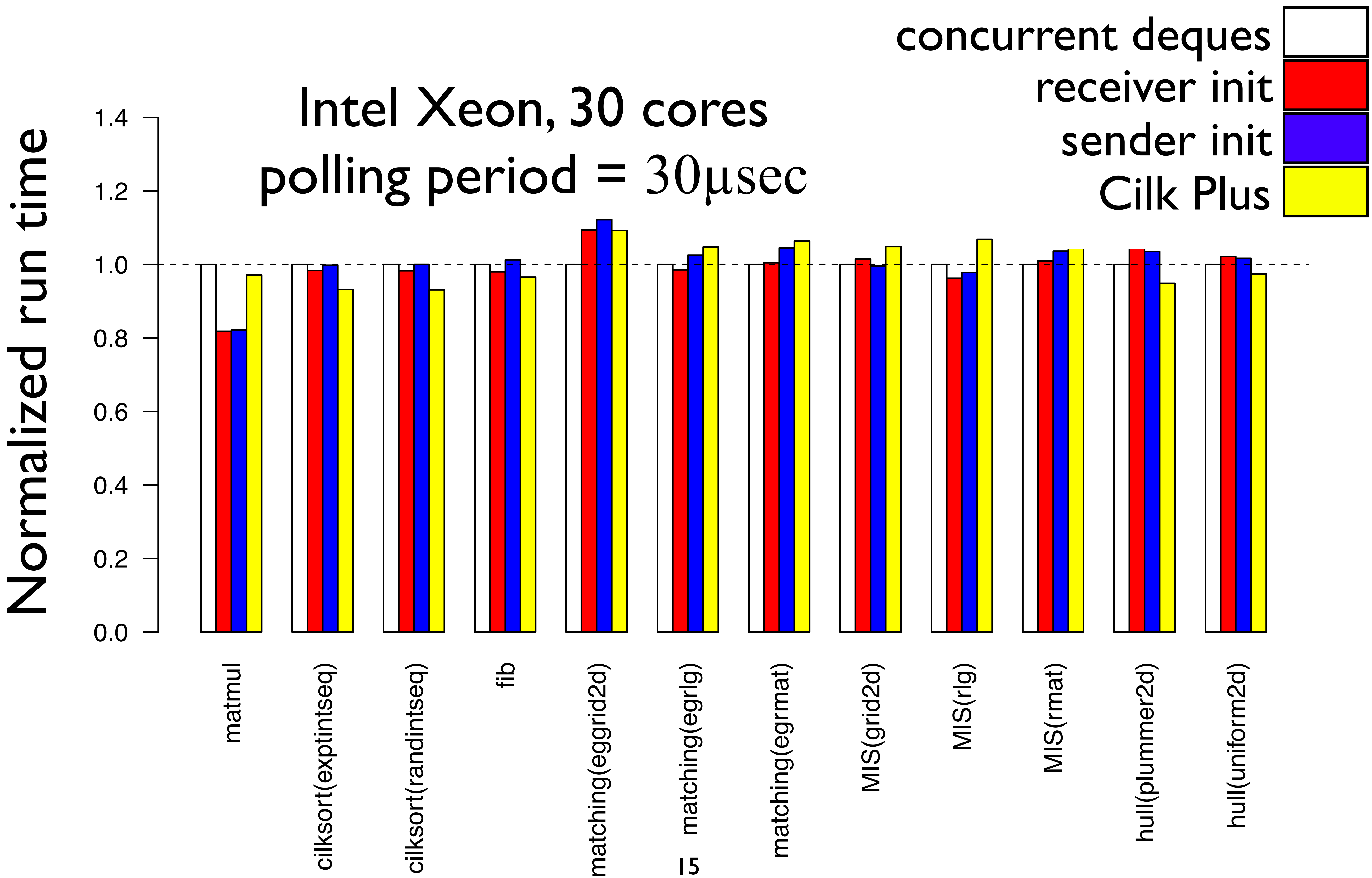
Performance study

- We implemented in our own C++ library:
  - our receiver-initiated algorithm
  - our sender-initiated algorithm
  - our Chase-Lev implementation
- We compare all of those implementations against Cilk Plus.

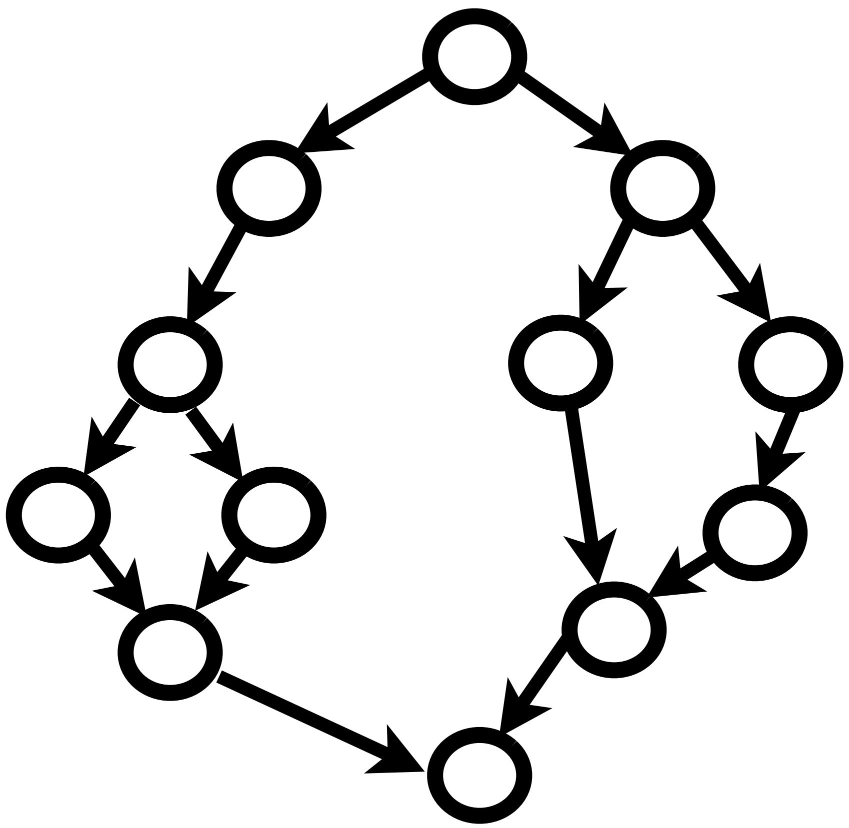
Benchmarks

- Classic Cilk benchmarks and Problem Based Benchmark Suite (Blelloch et al 2012)
- Problem areas: merge sort, sample sort, maximal independent set, maximal matching, convex hull, fibonacci, and dense matrix multiply.

Performance results



Analytical model



P	number of cores
T_1	serial run time
T_∞	minimal run time with infinite cores
T_P	parallel run time with P cores
δ	polling interval
F	maximal number of forks in a path

Our main analytical result

Bound for greedy schedulers:

$$T_P \leq \frac{T_1}{P} + \frac{P-1}{P} T_\infty$$

Bound for concurrent deques (ignoring cost of fences):

$$\mathbb{E}\left[T_P\right] \leq \frac{T_1}{P} + \frac{P-1}{P} T_\infty + O(F)$$

Bound for our two algorithms:

$$\mathbb{E}\left[T_P\right] \leq \left(\frac{T_1}{P} + \frac{P-1}{P} T_\infty + O(\delta F)\right) \cdot \left(1 + \frac{O(1)}{\delta}\right)$$

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Conclusion

- We presented two new private-deques algorithms, evaluated them, and proved analytical results.
- In the paper, we demonstrated the flexibility of private deques by implementing the steal half policy.