Towards Distributed Verification of Parametric Real-Time Systems

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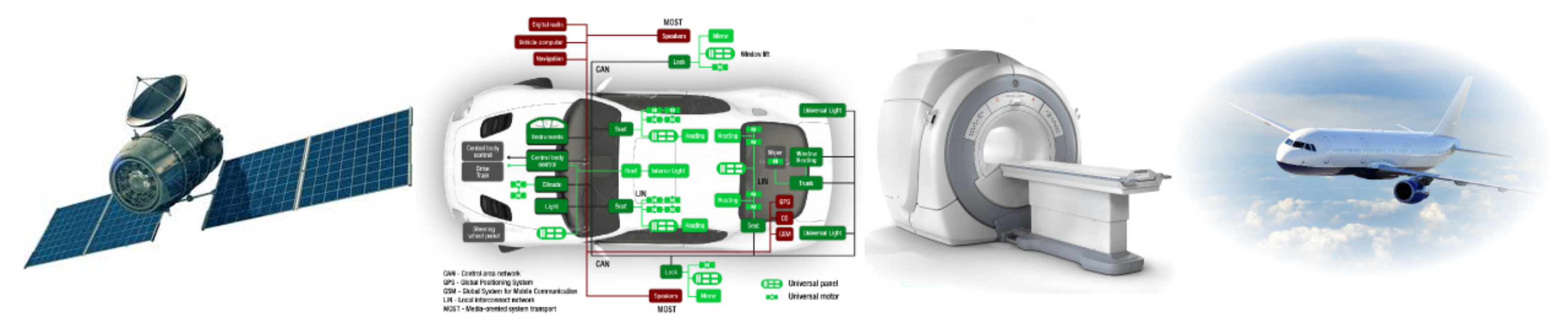
1. Context

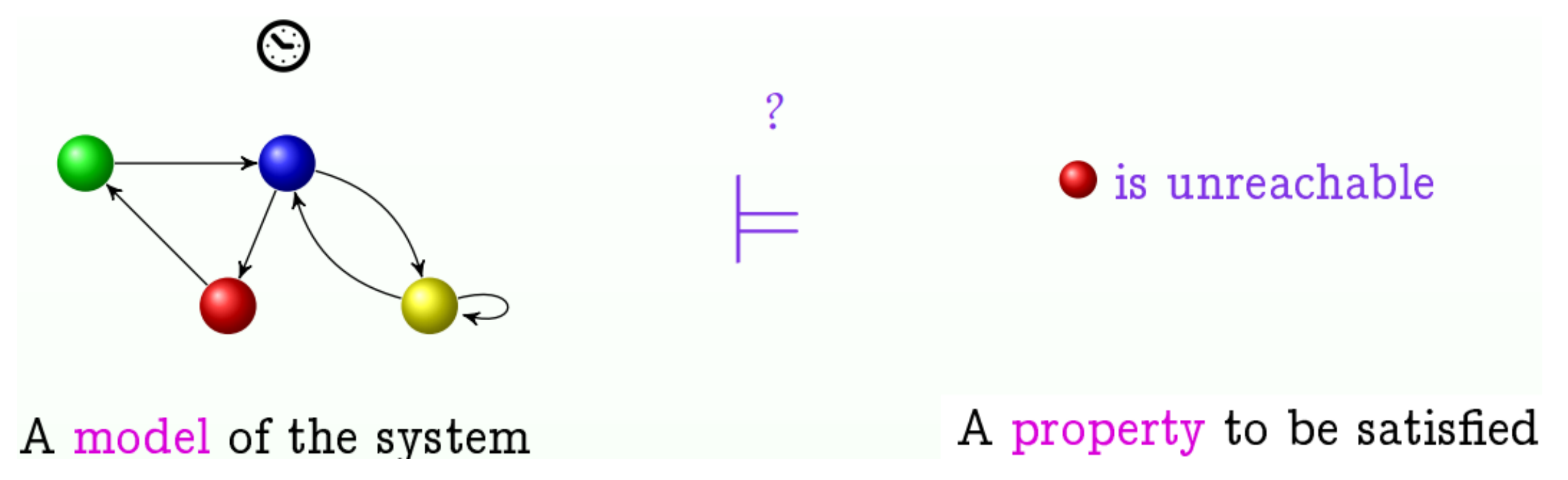
Real-time systems are difficult to test and their failure leads to dramatic consequences



Model checking is an automatic verification technique to verify the correctness of the system model w.r.t. a property:

- **Verification** procedure: exhaustive search of the state space of the model

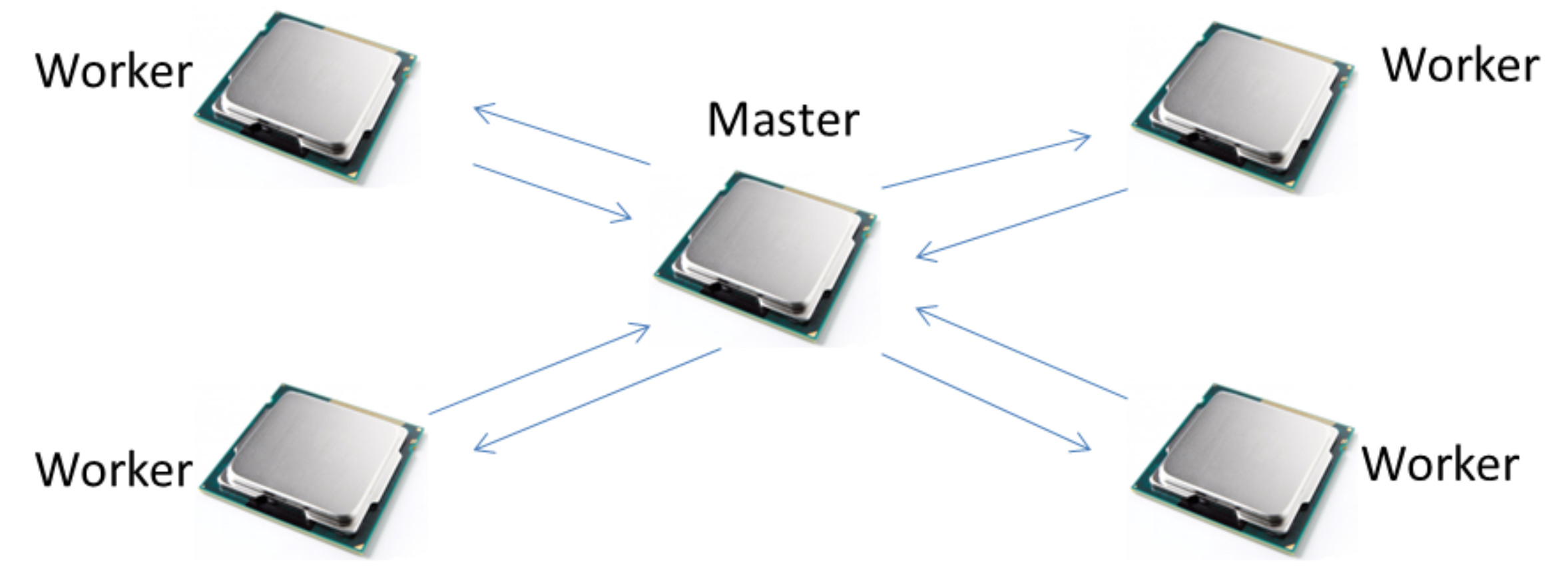
(State: ○; Transition: ⟶)



- **Checking question**: Does the model of the system satisfy the property?

2. Goal

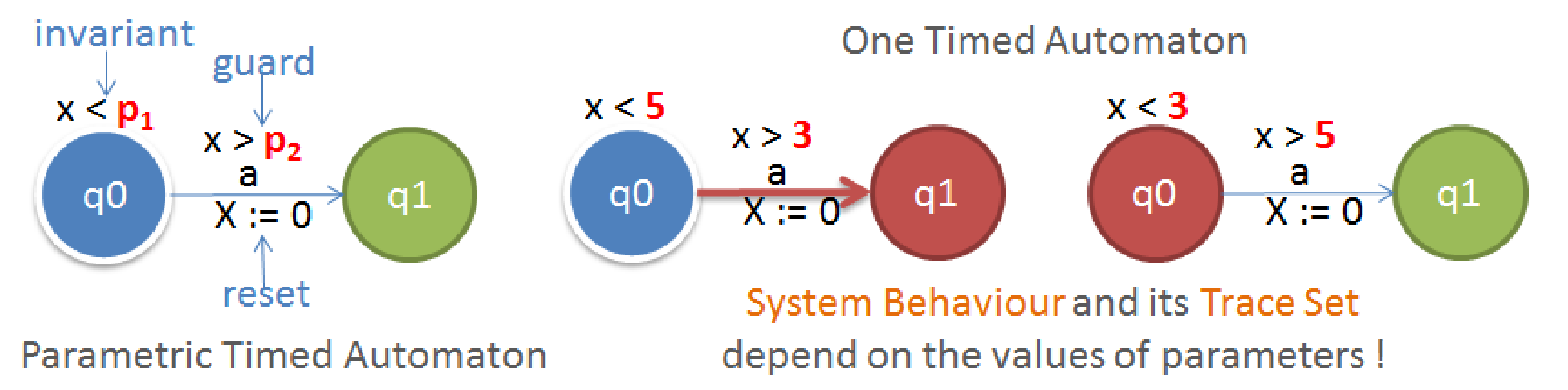
- Verify real-time systems, modelled by parametric timed automata. Take advantage of high-performance distributed computing for faster verification



→ Design algorithms distributed on a cluster to perform faster
(Note: Most algorithms use a Master-Worker scheme)

3. System model: Parametric timed automata

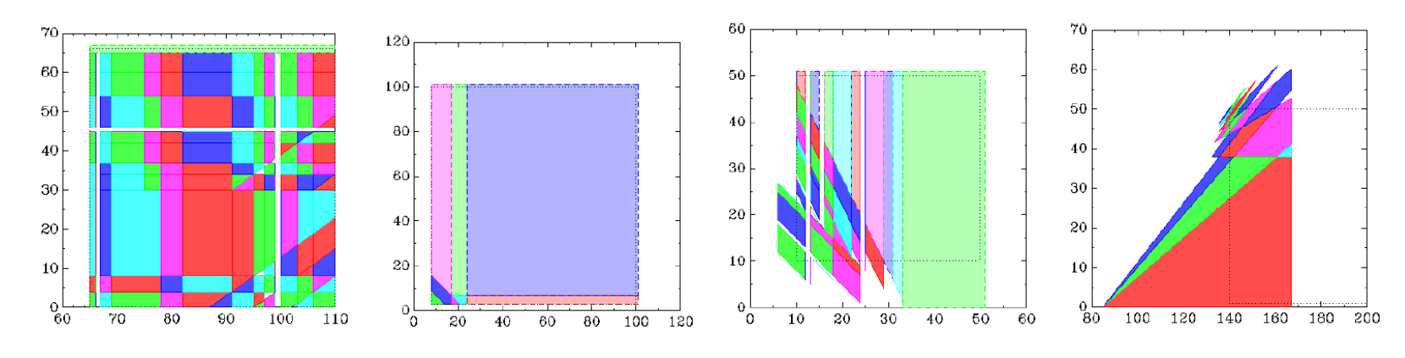
- A formalism to model and verify concurrent real-time systems [AHV93].
- 1 Parametric timed automaton (parameter) ↔ n.Timed automata (concrete value)



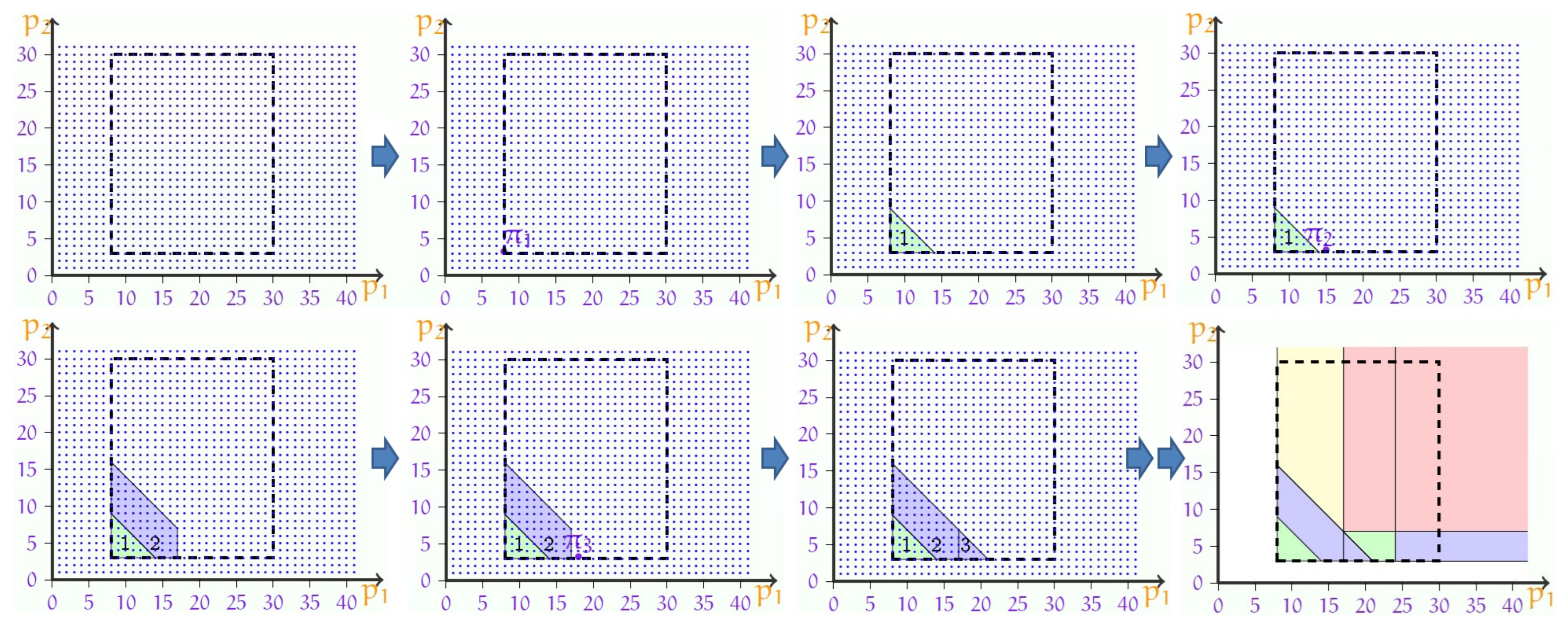
x: Clock
p: Parameters allow to represent unknown values (e.g. a transmission delay or a timeout)
Trace set: set of all sequences of (untimed) actions

4. Checking algorithm: Behavioural cartography

- Exhibit all subparts of the parameter space (system behaviours) (i.e. dense sets of parameter values of the parametric timed automata) [AF10]



- Easily check a certain value or a certain trace set for a certain behaviour

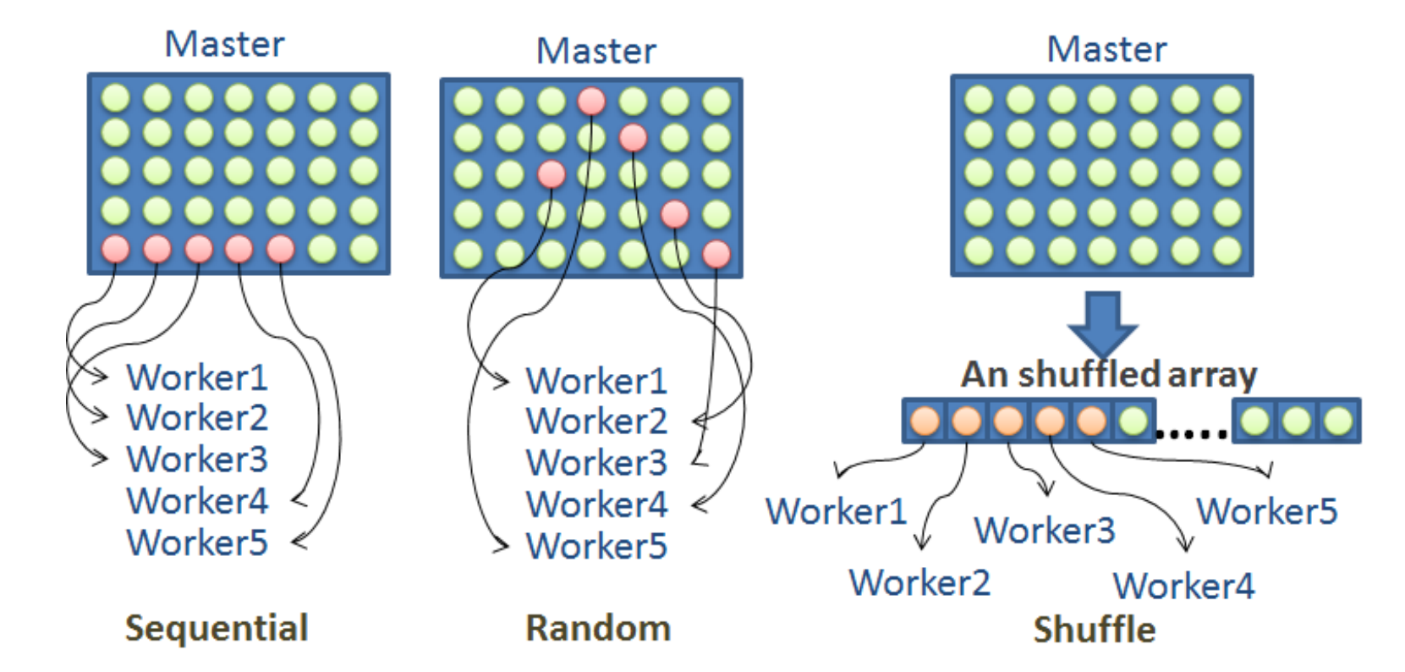


Method: Enumerate integer points and generate a tile (use the Inverse Method [ACEF09]). All points in a same tile have the same possible behaviours

5. Distribution: High performance distributed algorithms

Solution 1: Point-based distribution

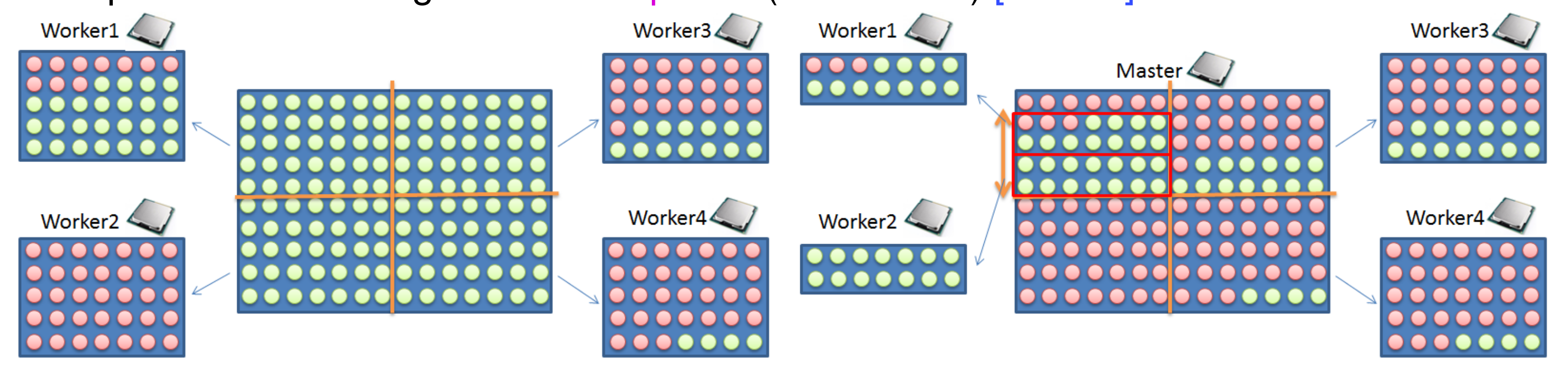
Master sends all the individual points to the Workers [ALN15, ACE14]. **3 algorithms:**



1. **Sequential:** Each point is sent to a worker sequentially
2. **Random:** Points are selected randomly, then switch to Sequential
3. **Shuffle:** Similar to Sequential, but the master must statically compute the array of all points, then shuffle all points, then store them back in the array (new!)

Solution 2: Region-based distribution

Each process is in charge of a set of points (subdomain) [ALN15]



Static:

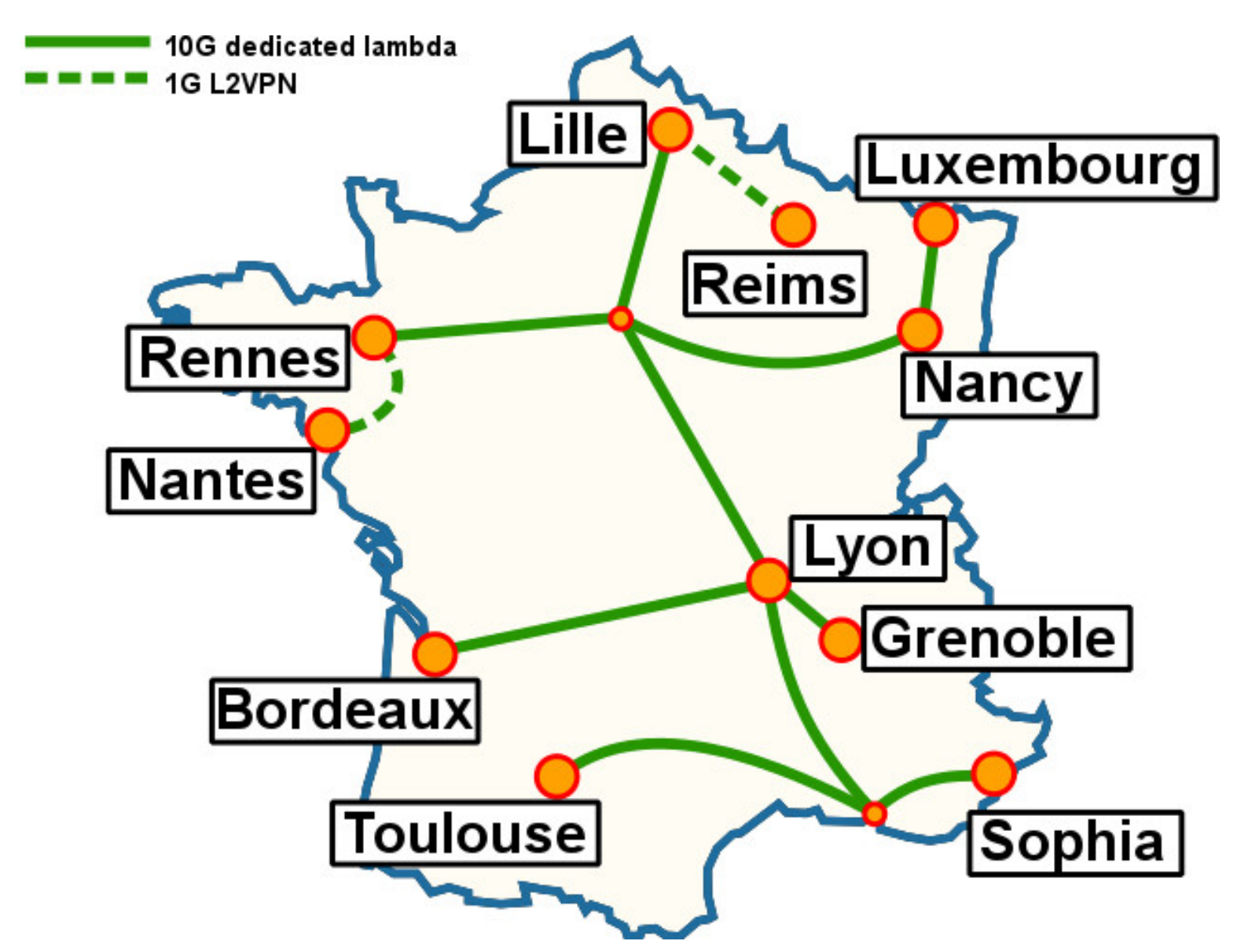
- One of the processes splits the domain, then sends to other processes and gathers the results of all processes
- Drawback: No load balancing although the workload is irregular

Dynamic:

- A Master is solely responsible for gathering tiles and splitting domain/subdomains
- The master monitors the progress of all workers: it can balance workload (by splitting) between workers

6. Implementation and experiments

- IMITATOR [André, Fribourg, Kühne, Soulat, 2012] : Parameter synthesis tool for real-time systems
- OCaml: All algorithms implemented in the OCaml language
- MPI: Using the OcamlMPI library bindings on top of Open MPI for message-passing between processes
- Grid'5000: homogeneous cluster featuring various technologies. Experiments conducted on 2 real clusters: Pastel (Toulouse, FR) 140 4-core nodes and Griffon (Nancy, FR) 92 8-core nodes



The case studies are a flip-flop circuit, a root contention protocol, some tasks scheduling problems and a networked automation system:

Case study	Flip-flop4	RCP	Sched3-2	Sched3B-2	Sched3B-3	Sched5	SiMoP
Execution time							
Static	33.0	2108.0	4.0	26.6	181.0	213.0	21.4
Seq	2059.0	653.0	4.6	11.0	810.0	219.0	36.1
Random	652.0	635.0	3.6	8.4	524.0	148.0	23.6
Shuffle	670.0	624.0	3.1	7.6	243.0	140.0	18.7
Subdomain	48.0	1286.0	7.2	15.8	217.0	273.0	32.4
Subdomain + H	24.0	622.0	4.0	11.0	81.0	199.0	23.2
Hybrid	24.0	624.0	3.1	7.6	81.0	140.0	18.7

Hybrid: switch between Subdomain + H (≥100.000 points) and Shuffle (<100.000 points)

7. Conclusion and future works

- Proposed a new efficient distributed algorithm + Heuristic for Behavioural Cartography
- Implemented the new algorithms in IMITATOR

- Design an fully distributed scheme for BC (No Master!)
- Try BC in GPU's or CPU+GPU's environments
- Formally prove the deadlock-freeness of our master-worker communication scheme

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