Parallel Agent Based Simulation on PC Cluster

Seif Haridi
Konstantin Popov
Mahmoud Rafea
Fredrik Holmgren
Swedish Institute of Computer Science
www.sics.se/~seif
seif@sics.se

Abstract Architecture

- Scenario
  - Agents
    - Behavior
    - State
  - Landscape
    - Placeholder
    - Physical Space
- Simulation System
  - Simulation Manager
    - Interaction
    - Scheduling
  - Workers
    - Behavior invocation
  - Monitors
    - Track behavior

Example simulation model

- A bottom up agent based simulation
- Agents: users, sites representing web surfers, and web sites
- Landscapes: users are connected in Small World network (social network, 1-lattice), sites are connected in a similar network
- The model of time is discrete
- The implementation system is Mozart, language is Oz (http://www.mozart-oz.org)

Oz and Mozart at a glance http://www.mozart-oz.org

- Oz Language
  - Multiparadigm language, strong support for compositionality and concurrency
  - Component-based programming
  - Simple formal semantics and efficient implementation
- Strengths
  - **Concurrency**: ultra lightweight threads, dataflow
  - **Distribution**: network transparent, network aware, open, fault detection
  - **Inferencing**: constraint, logic, and symbolic programming
  - **Flexibility**: dynamic, no limits, first-class compiler

Web Word of Mouth Model

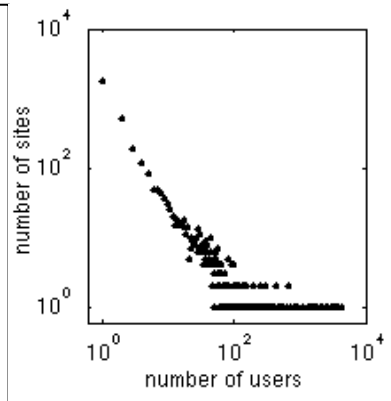
User characteristics:

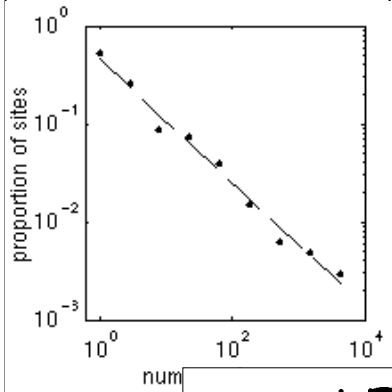
- Have preferences for specific categories of content
- Participate in "local" social networks
- Maintain a portfolio of frequently visited sites
- Have memory about visited sites and their perceived utility
- Have an evaluation method in order to evaluate sites they visit.

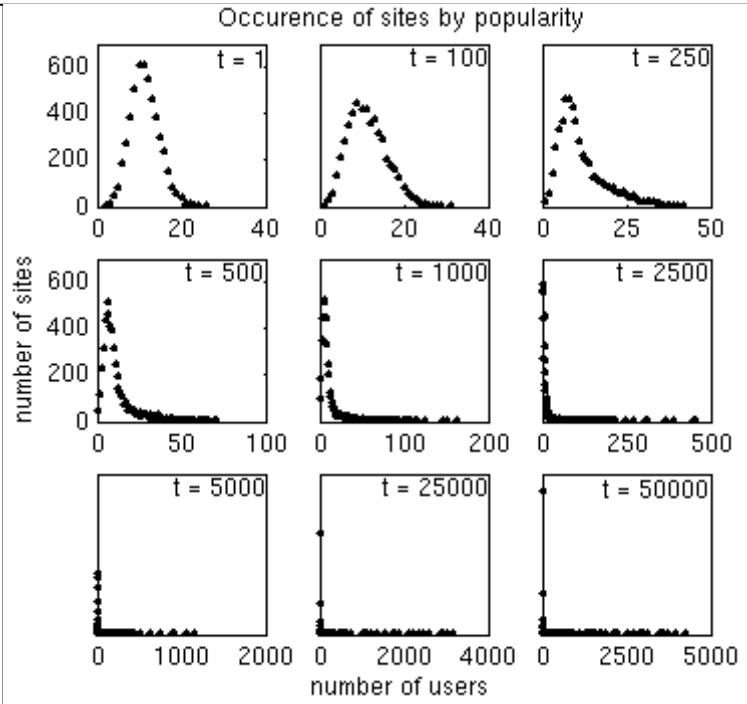
User behavior

- Asks friends to propose their favorite sites and visit them.
- Visits some sites from his portfolio.
- Surf along the links of the already visited sites.
- Replace a site in the portfolio by a new site if that new site maintained a higher utility for a longer period of time.

Model dynamics







LEFT: Distribution of web sites by size

RIGHT: Progressive evolution of the histogram "number of sites/number of users" towards a power-law distribution

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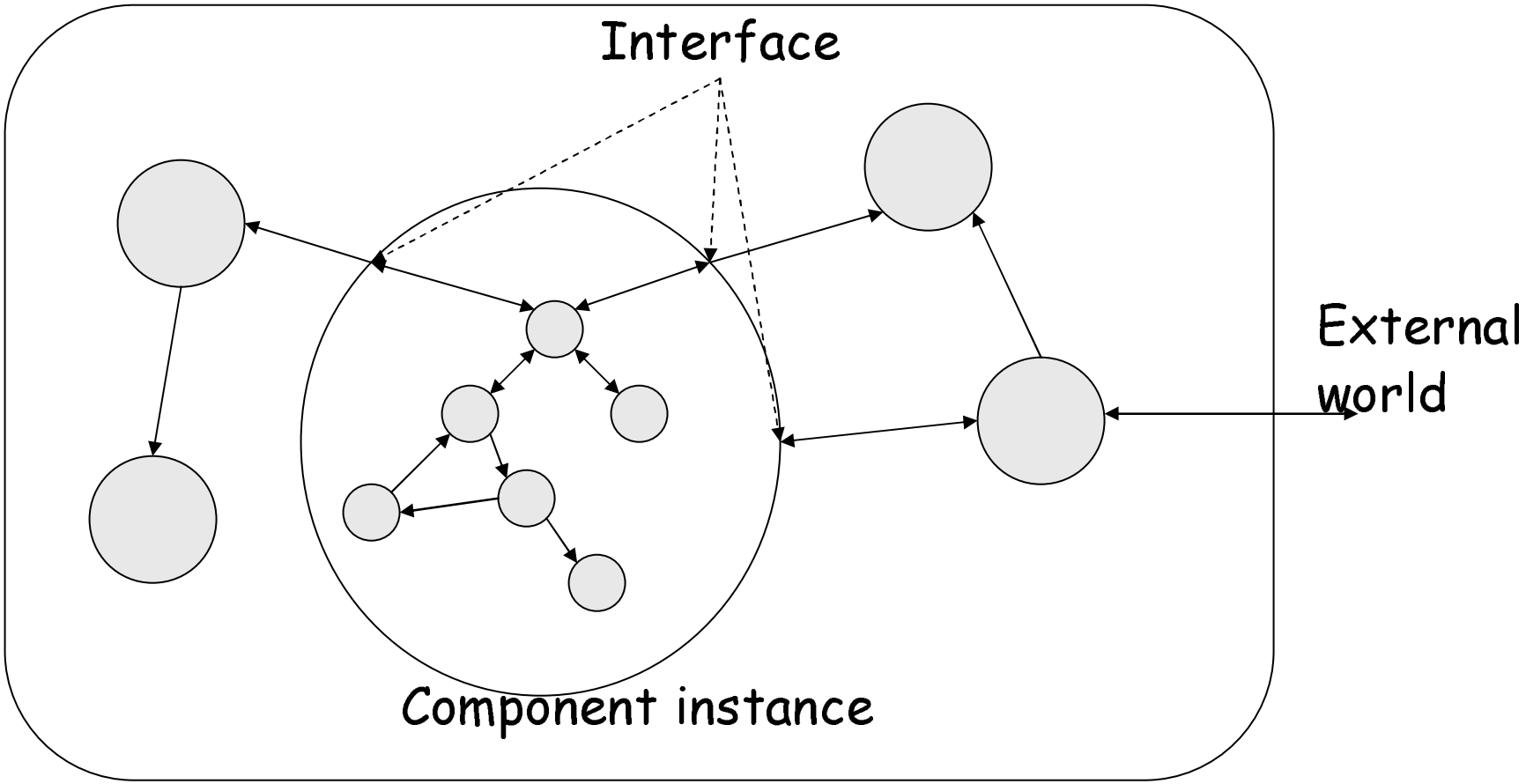
Component-based Programming

- Implements abstract data-types
  - Encapsulation of internal state
  - Interface of external operations
  - Instantiation (component instances, modules)
- Compositionality
  - Specifies **required** (imported) components in terms of their operations only
  - Decouples linking of the exact modules from import specification.
  - Connecting component instances are done by the component-manager at runtime (allows linking different component instances depending on runtime conditions

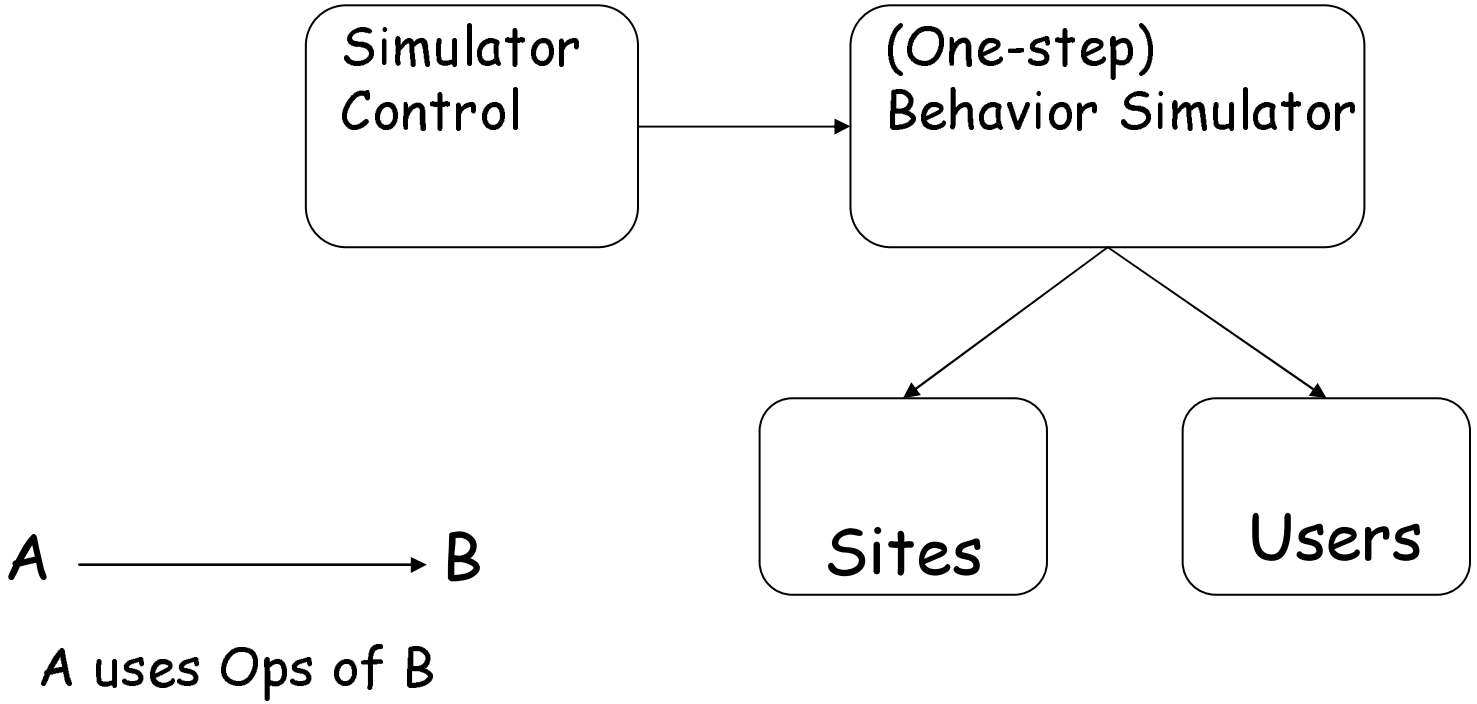
Component-based Programming



Sequential Simulator Components

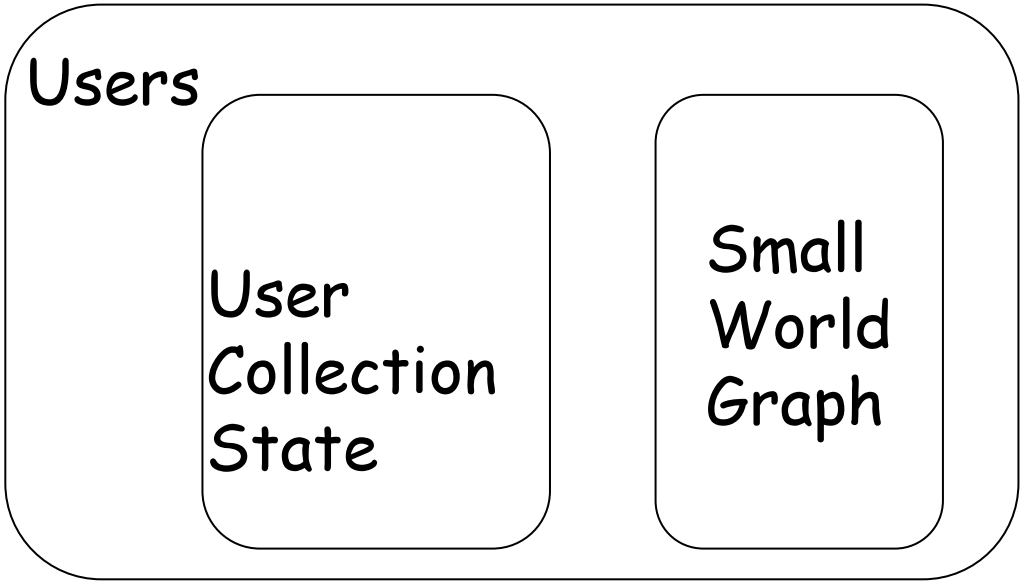
- Landscape
  - Small World (SM) graph
  - Internet Sites (IS) graph
  - Other graphs
- Agent state collections (set of agents)
  - Users collections, and Sites collections
- Agents behaviors
  - ExploreSites, GetRecommedations, UpdatePortfolio, etc

Architecture Sequential - Simplified (component instances)

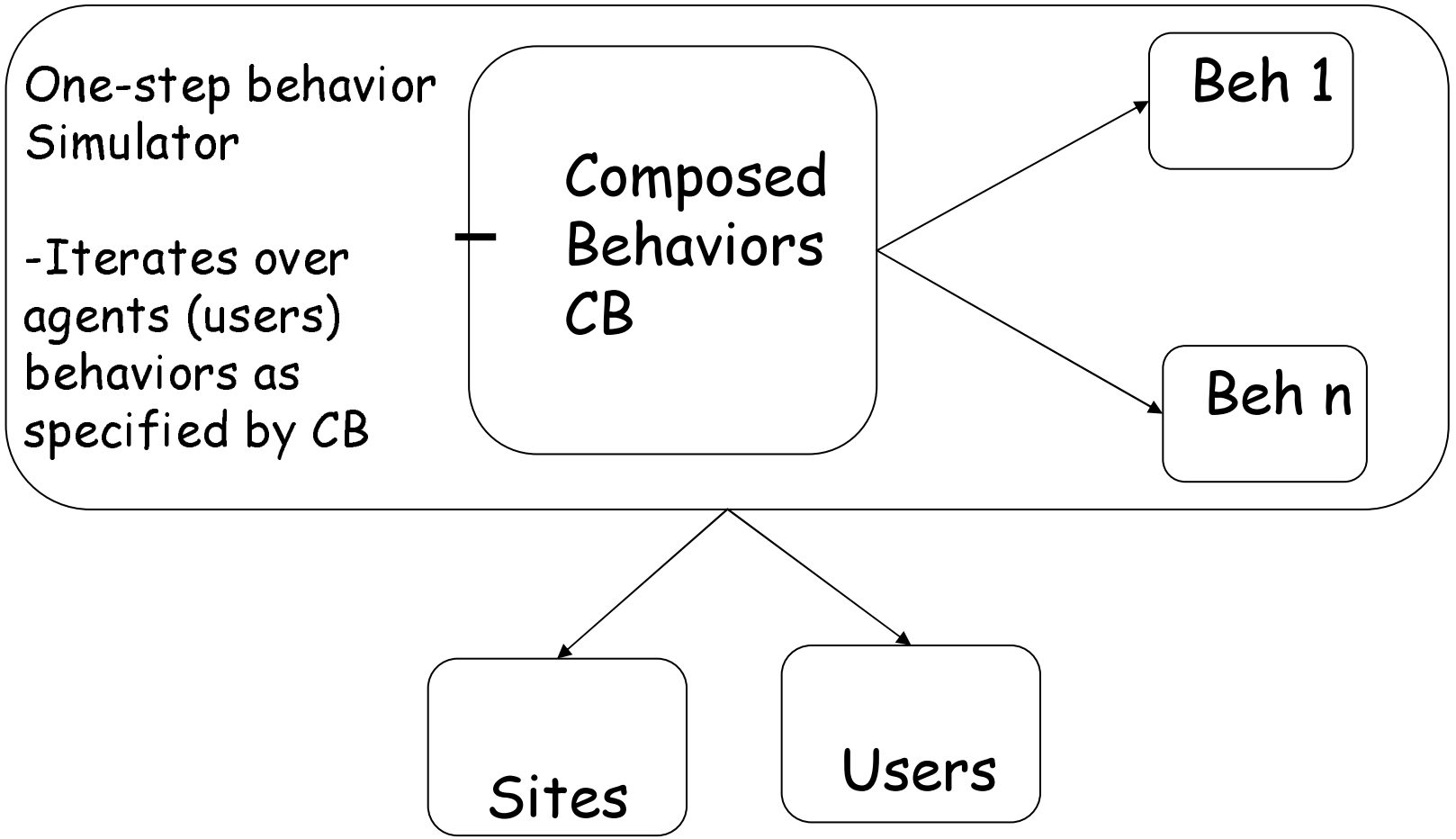


Users

- Places the User agents on the SW graph
- Provides the Ops. of the Users abstract data-type needed to express behaviors
- Sites done in similar way



Behavior Simulator



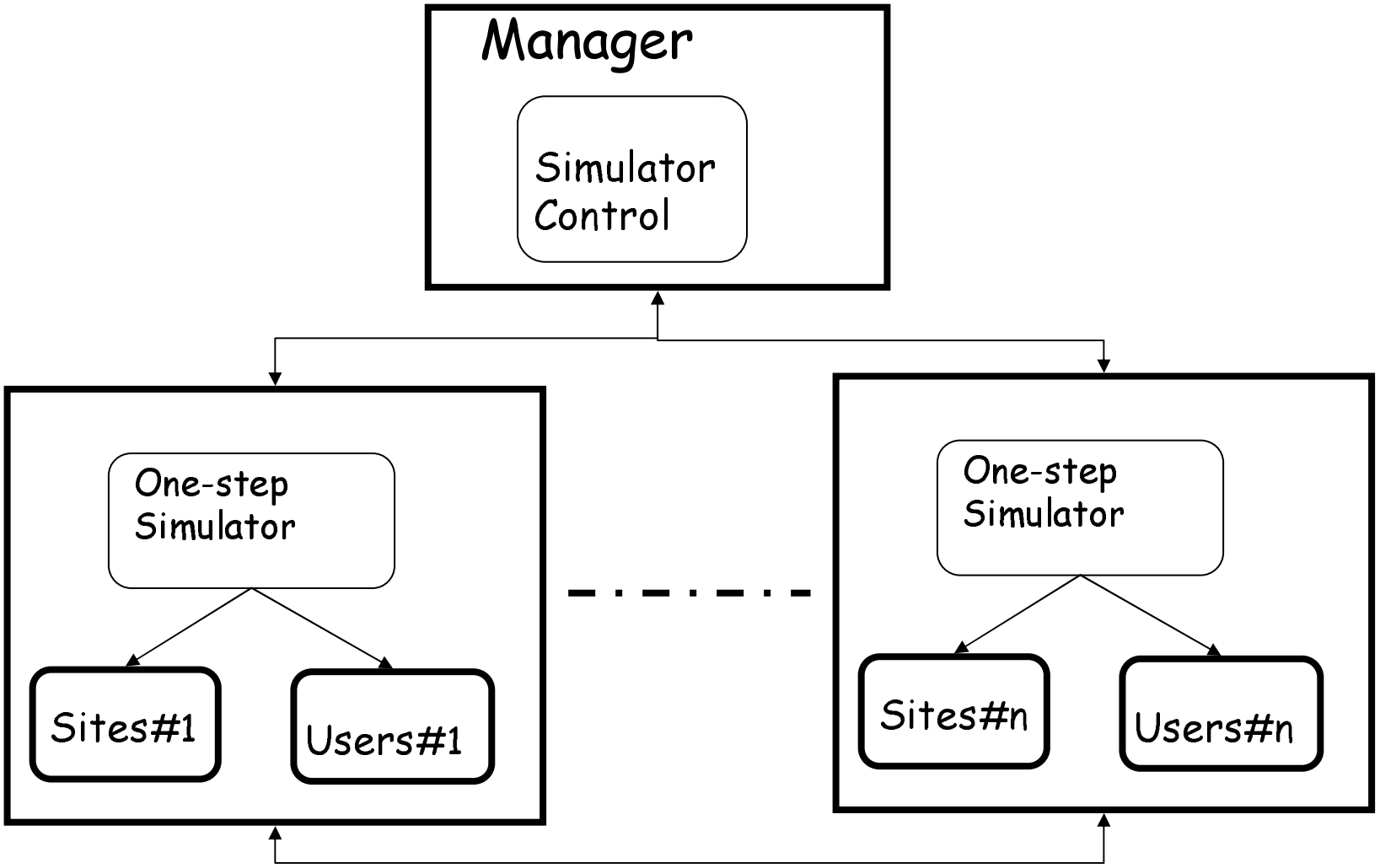
Parallel Simulator Requirements

- **Goals**
- Goal: 1000000+ sites/users, 1000+steps AFAP
- Today's sequential system takes ≈1min for 10000 sites/users +100 steps on a 1Ghz processor
- WORSE: *at best* linear memory requirements: ≈ 0.25Gb per 100000 sites/users
- Developing techniques & tools for high performance parallel computation in Mozart
- Study and improvement of [distributed] Mozart

Parallel Simulator

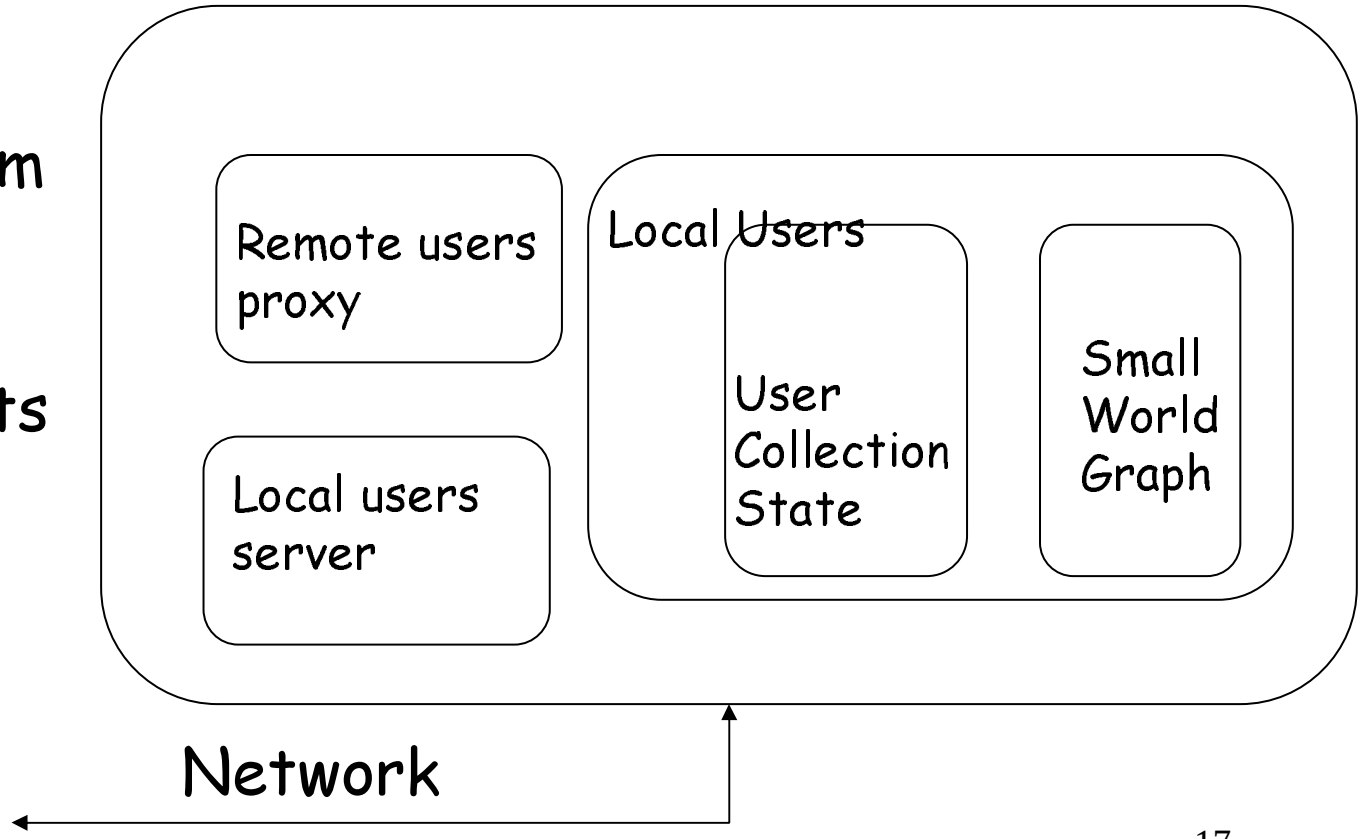
- Sites and Users collections are partitioned among N computers (N workers)
- A Manager computer is responsible for creating Sites and Users component instances and partitioning them to the workers according to their relative performance
- The behavior-simulator component is unchanged
- The User and Sites component instances are wrapped using a distribution abstraction that allows transparent access to remote user-agents and site-agents

Architecture Parallel Simulator



Distributed Users

- Abstracts the network
- Services requests from remote workers
- Send requests from local worker to remote ones



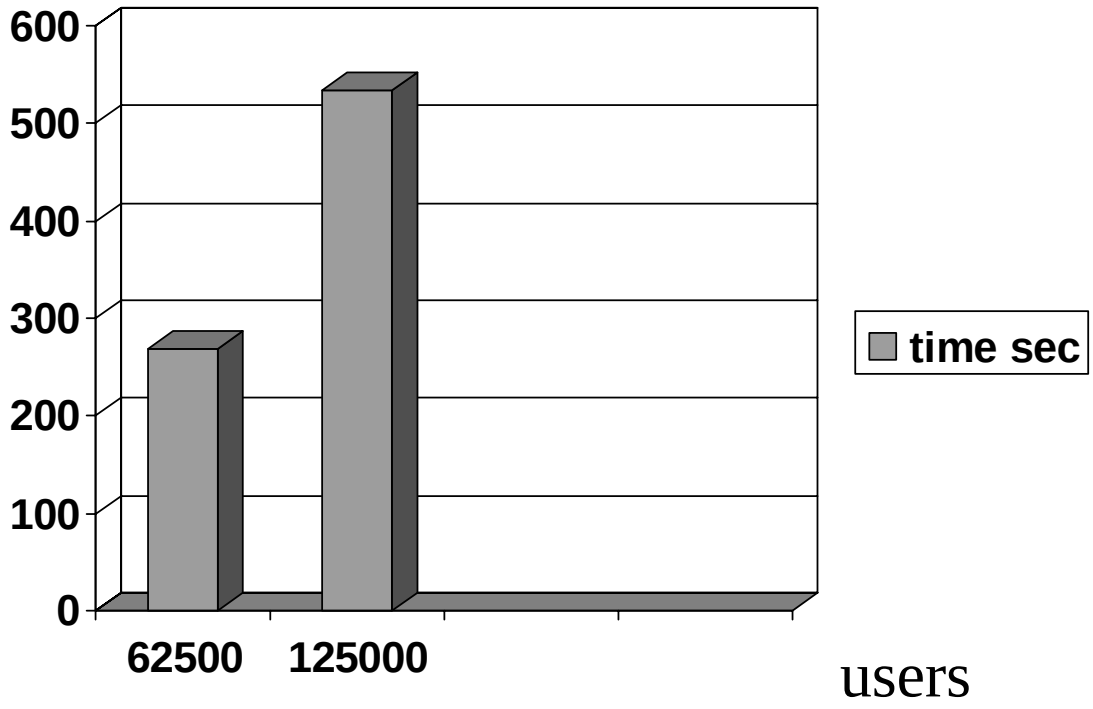
Simple set-up

- Manager partitions user and site agents according to the workers performance
- Manager initiates work at each time step
- Each worker performs the work as specified by its one-step simulator
- Workers report to manager at the end of each time step
- This process is reiterated

Ways of performing Ops. on agents (sites/users)

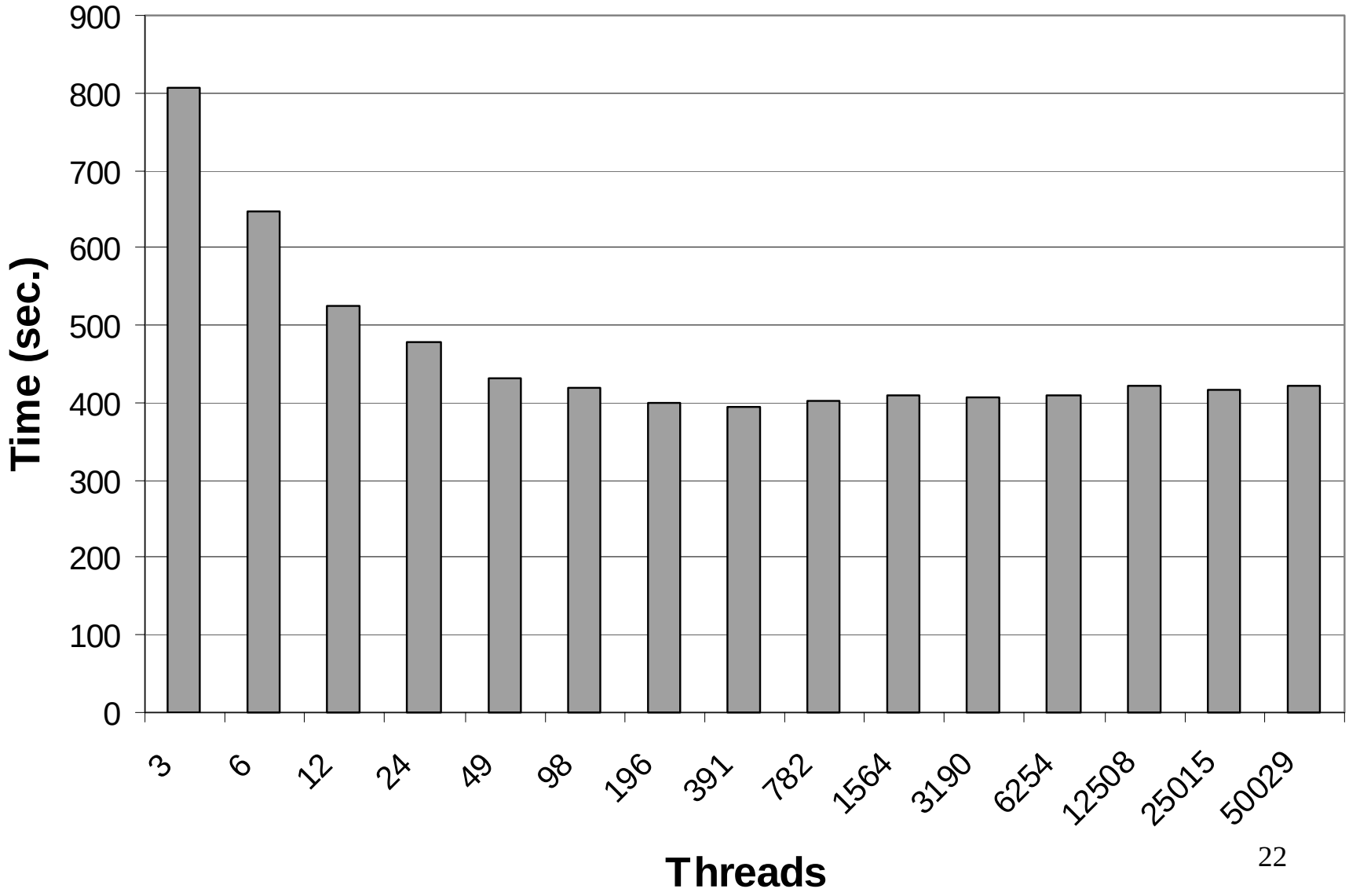
- Remote (operation to data)
  - A request to perform an operation on a site/user is sent to the responsible worker
- Replication (data to operation)
  - State of agent is replicated to requesting site
  - Works for stateless (immutable) data
  - Eager / Lazy
- One-Step Caching (data to operation)
  - State is cached at the worker when requested
  - State updates are done locally
  - At the end of a simulation step operations are merged/performed at the agent's worker
  - The cache is evicted (cleaned)

Sequential, 10000 sites users/time



Threading the Behavior Simulator (BS)

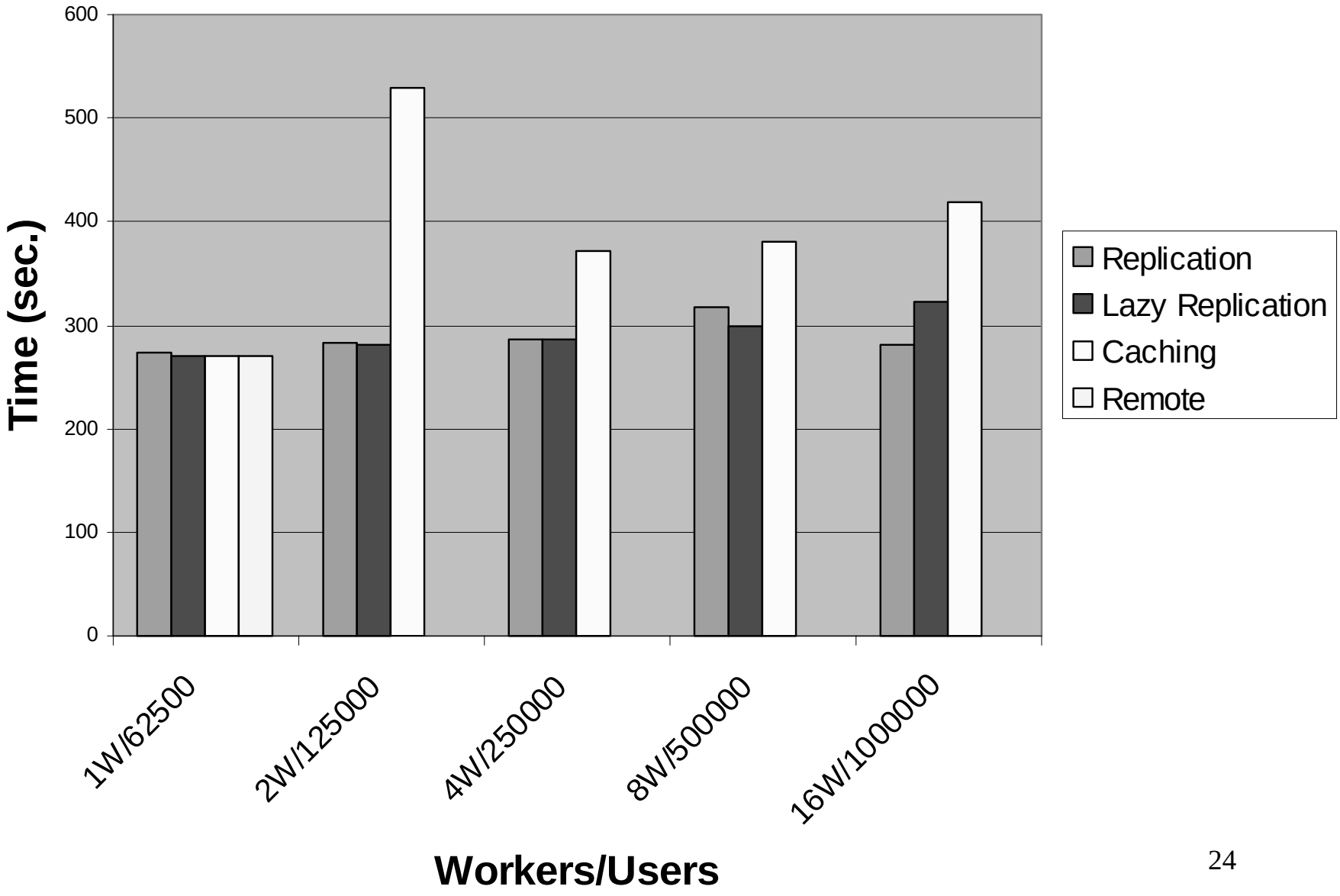
- Sequential BS is running a single thread
- In the Parallel Simulator, multiple threads are executed to hide network latency
- This can be done in Mozart without changing 'Behaviors' due to Mozart's dataflow property
- A thread issues operations sequentially, blocks transparently on variables until bound
- How many threads per worker? depends on network latency


Number of Threads
Time (sec.)
900
800
700
600
500
400
300
200
100
0
3
6
12
24
49
98
196
391
782
1564
3190
6254
12508
25015
50029
Threads

Scalability

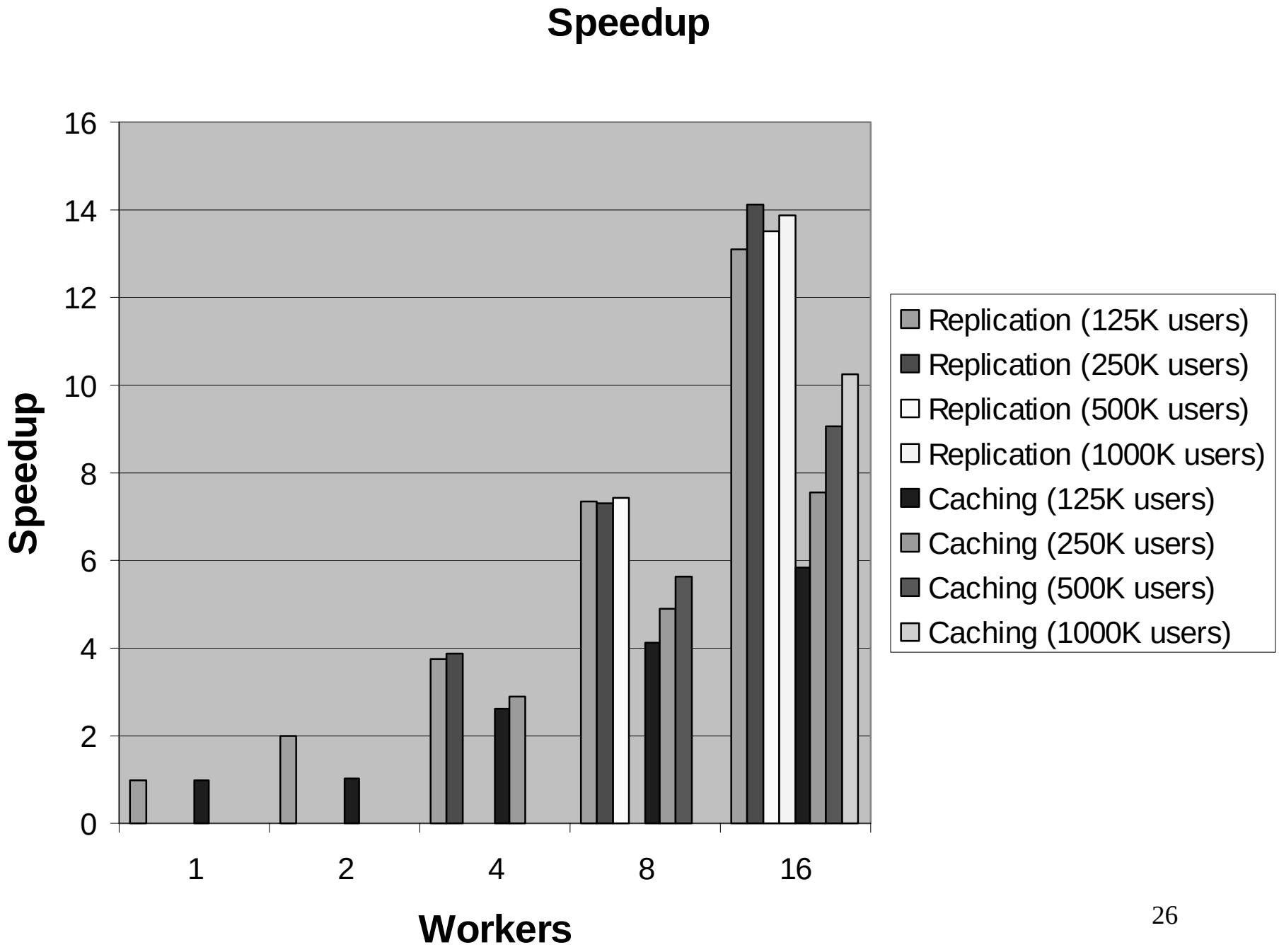
- We Want to study the scalability of the example application w.r.t. Problem size.
- As can been seen on next slide 1000K agents/ 16 workers experiment take similar time as 62,5K agents/one worker

Scalability



Speed-up

- The speed-ups are good.
- The most general case with one-step caching obtains 10 times speedup on 16 workers.
- The speedup increases with larger problem size.


Speedup
Speedup
16
14
12
10
8
6
4
2
0
1
2
4
8
16
Workers
Replication (125K users)
Replication (250K users)
Replication (500K users)
Replication (1000K users)
Caching (125K users)
Caching (250K users)
Caching (500K users)
Caching (1000K users)

Dataflow synchronization

- A worker at step N can serve requests for steps N-1, and N
- Serving a request at step N+1 state is delayed until the worker advances to N+1
- For any worker at step N, each other worker is either in step N-1, N , or N+1

Dataflow synchronization

- At the end of step N-1, a worker sends a sync(N) message to all other workers
- The worker waits for all sync(N-1) messages from all other workers, before starting step N
- For any worker at step N, each other worker is either in step N-1, N , or N+1

Barrier vs. Dataflow Synchronization

- 10k sites, 1M users, caching, 16 workers
  - 426 sec. with dataflow synchronization
  - 500 sec. with barrier synchronization

Synchronous Garbage Collection

- 10k sites, 1M users, caching, 16 workers
  - 426 sec. with synchronous GC
  - 491 sec. with asynchronous GC

Conclusions

- Component-based programming is essential for flexible agent-based bottom-up simulation.
- It is possible to simulate large number of agents 1000k agents using the right techniques on cheap PC clusters
- Mozart's network transparency, dataflow synchronization, light-weight threads and component-based techniques eases the application development