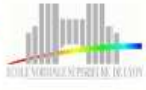
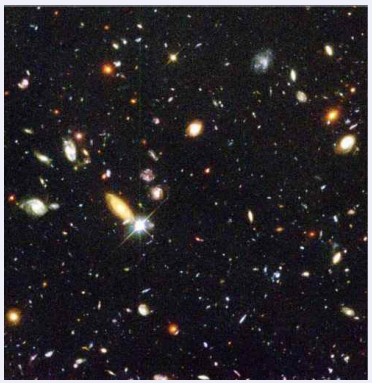
Peer-to-Peer Prefix Tree for Large Scale Service Discovery

Cédric Tedeschi

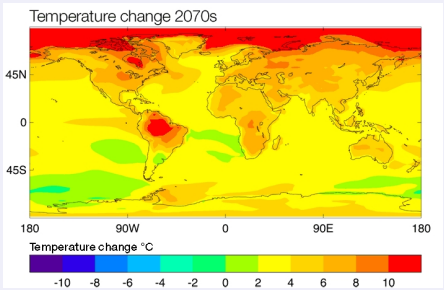
October 2, 2008



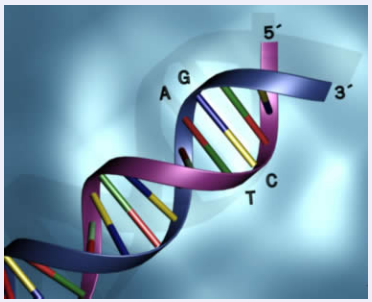

Computing Needs



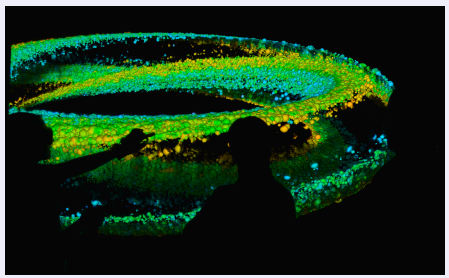
Cosmology



Climate prediction



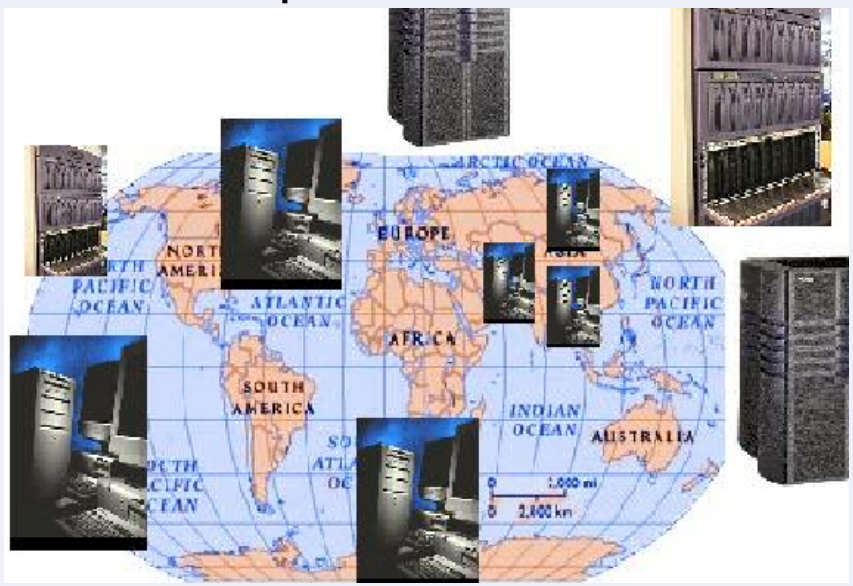
Genomics

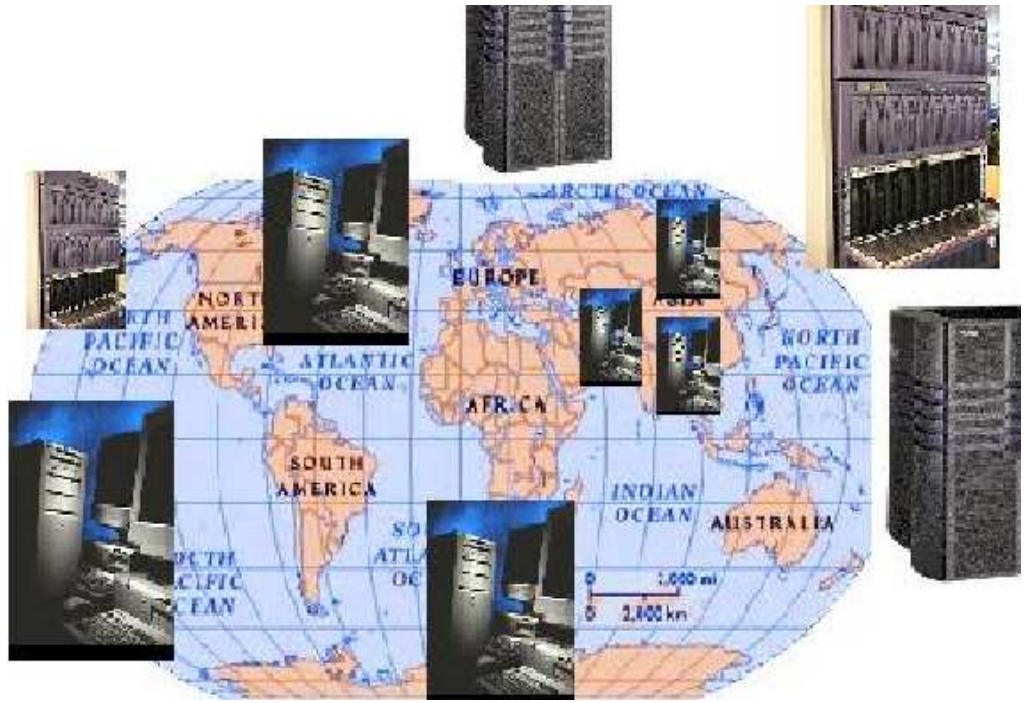


Nuclear security

Computing Power

Computational Grids

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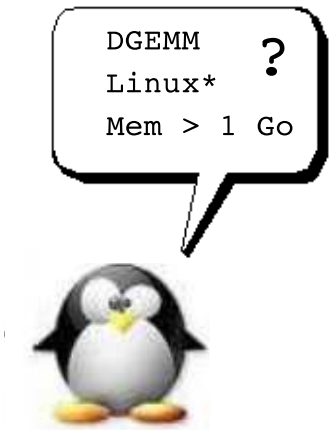
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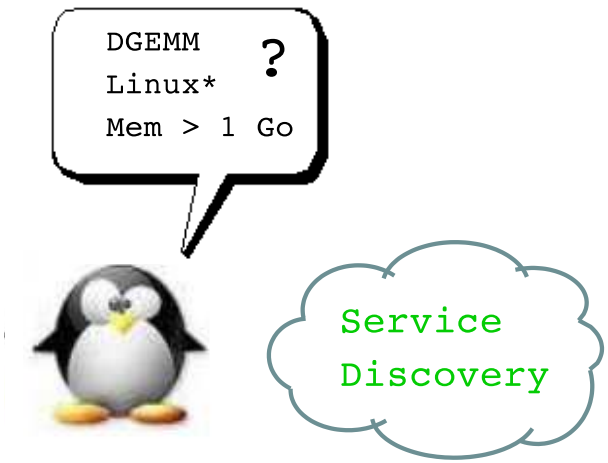
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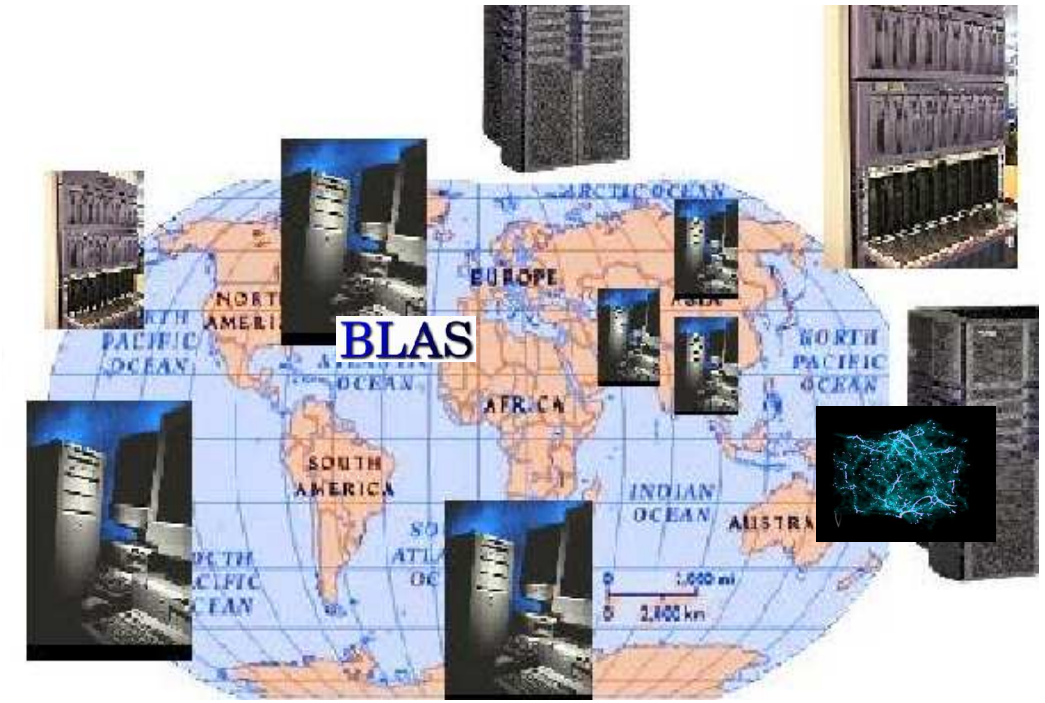
Service
Discovery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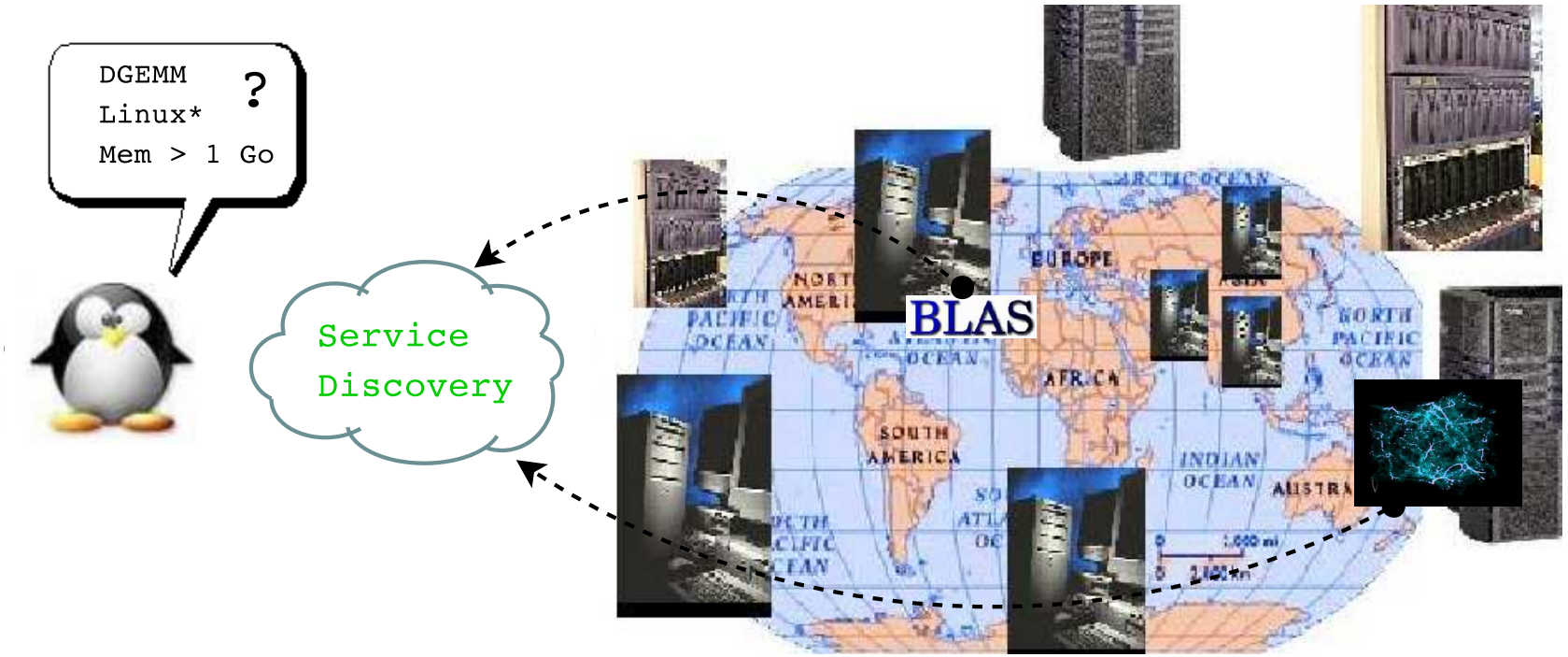
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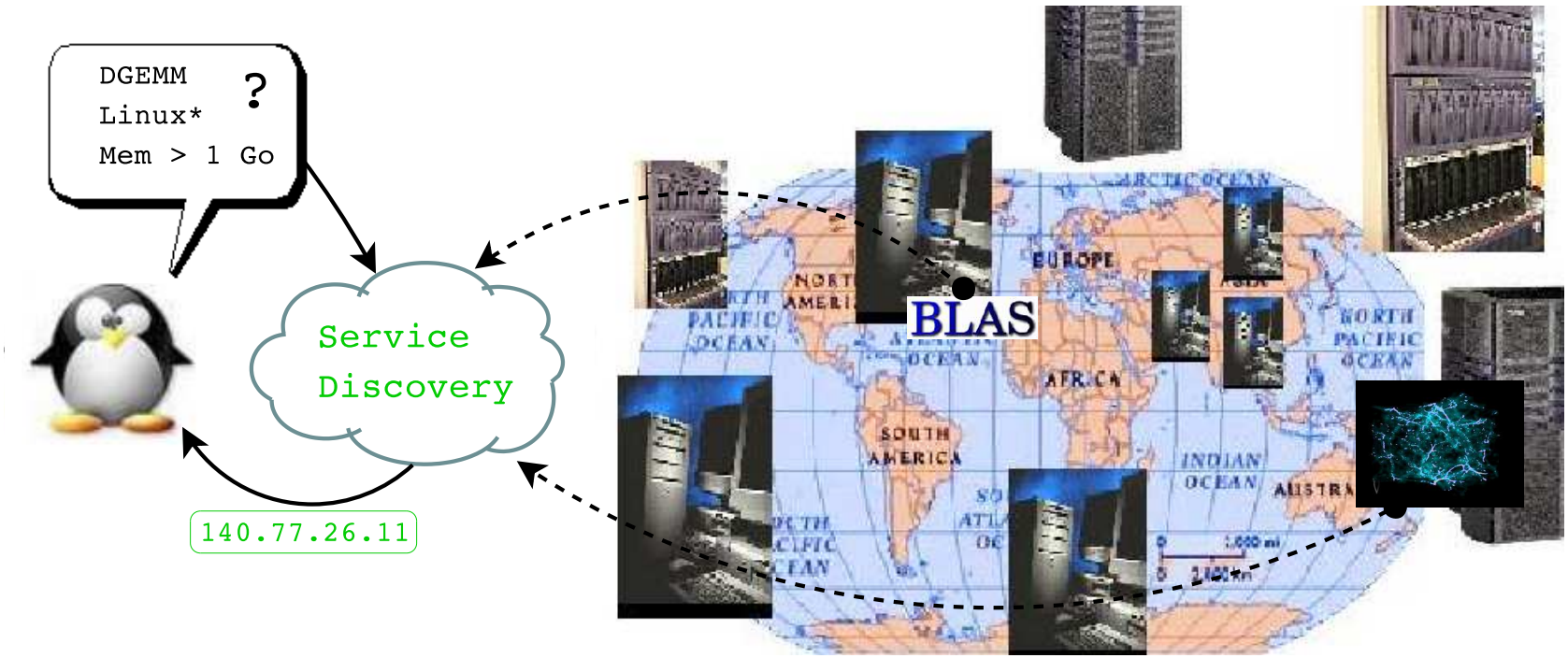
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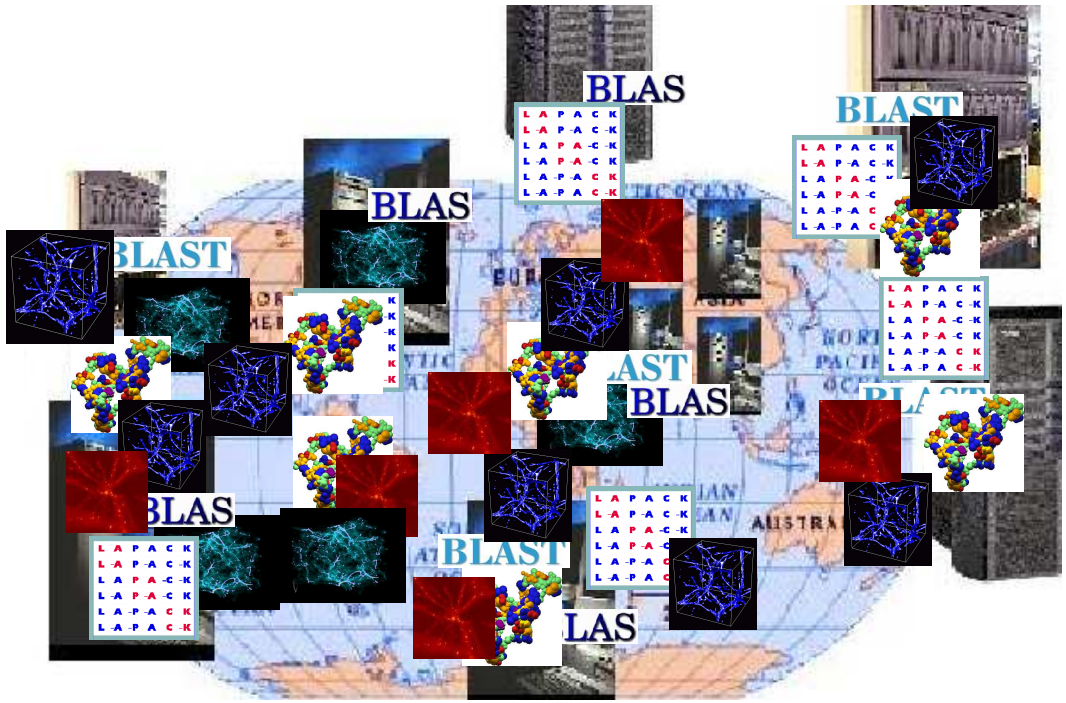
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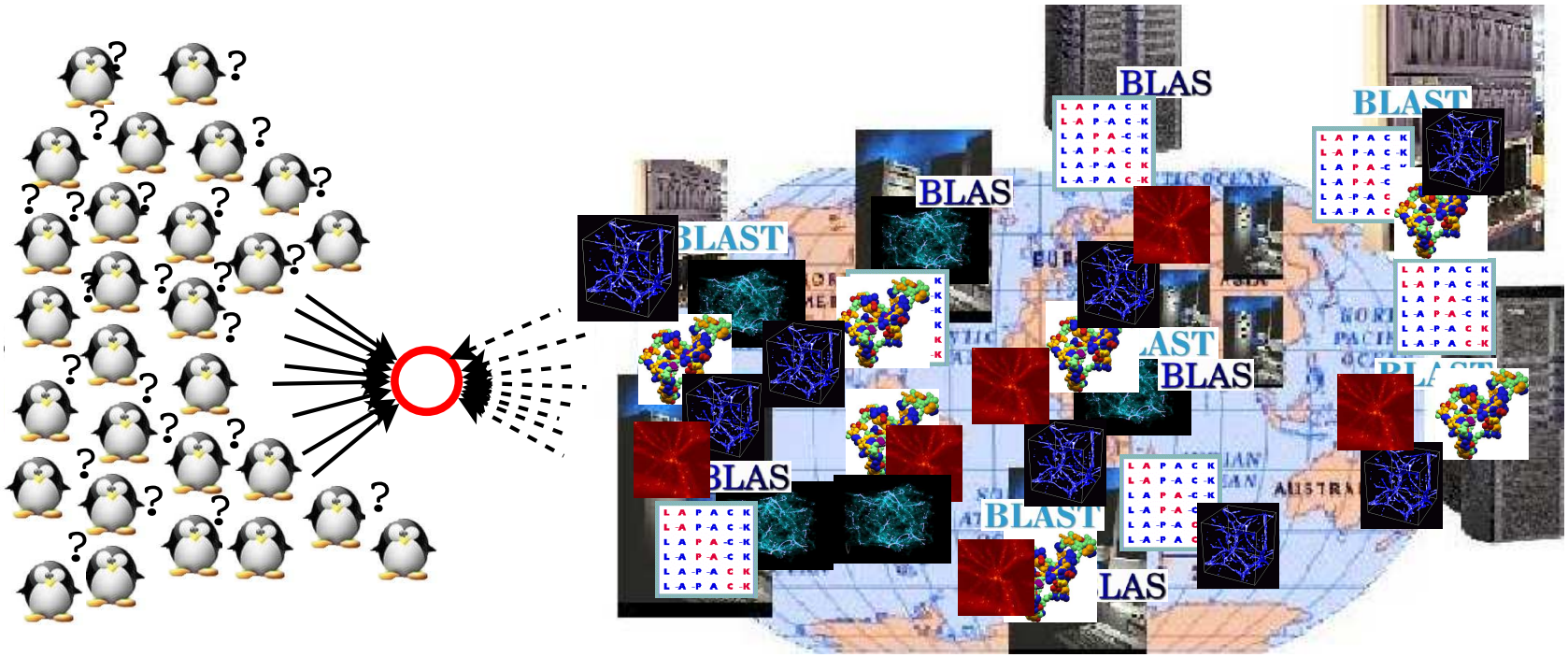
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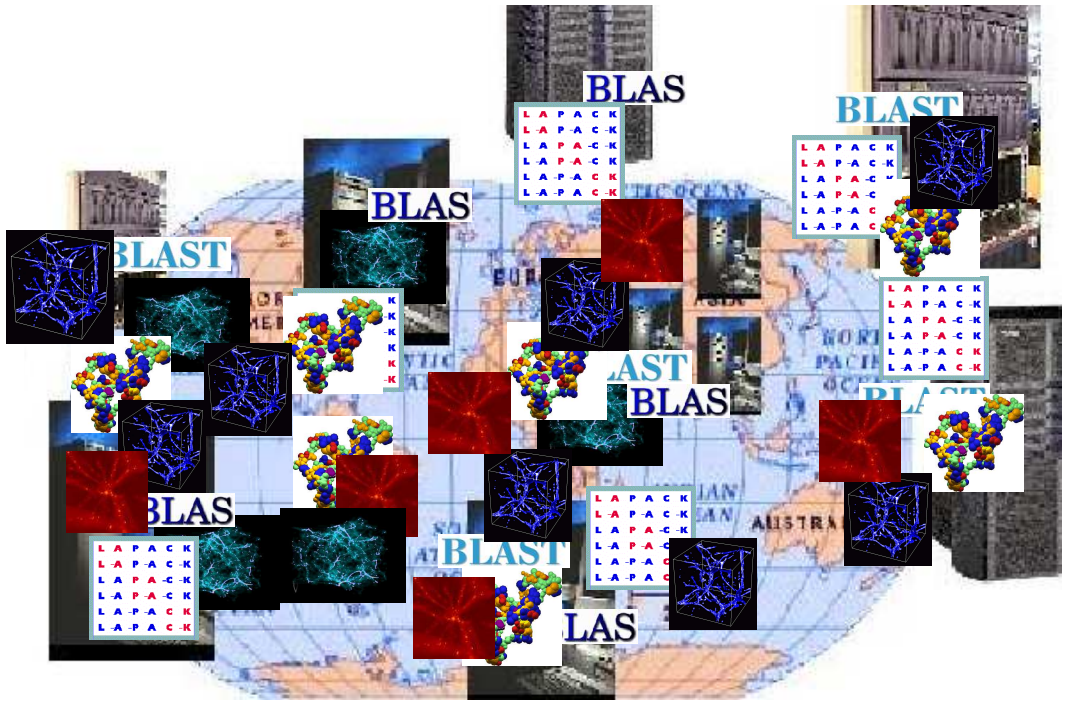
P2P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P2P Information Retrieval (review)

Unstructured (Gnutella)

- Flooding
- Cost
- Non-exhaustiveness

Structured (DHTs)

- Routing
- Exhaustiveness
- Scalability
  - Logarithmic state
  - Logarithmic path
- Drawbacks
  - Exact queries only

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Objectives

A P2P structured solution with

- Expressiveness
  - Range queries
  - Automatic completion
  - Multi-attribute queries
- Efficiency in a P2P environment
  - Heterogeneous $\Rightarrow$ Load balancing
  - Dynamic $\Rightarrow$ Fault-tolerance

Outline

1. DLPT : a Trie-Based Solution
2. Mapping & Load Balancing
   - Protocol
   - Load Balancing
   - Simulation
3. Fault-tolerance
   - Snap-Stabilizing PGCP Tree (State Model)
   - Self-Stabilizing PGCP Tree (Message-Passing Model)
4. Prototype Implementation
   - Design
   - Early Experiments
5. Summary & Open Problems

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DLPT : A trie-based indexing system

Distributed Logical Structure

- Greatest Common Prefix Tree
- Dynamically constructed
- Bounded degree and height

Definition

Each node is the greatest common prefix of any pair of its children

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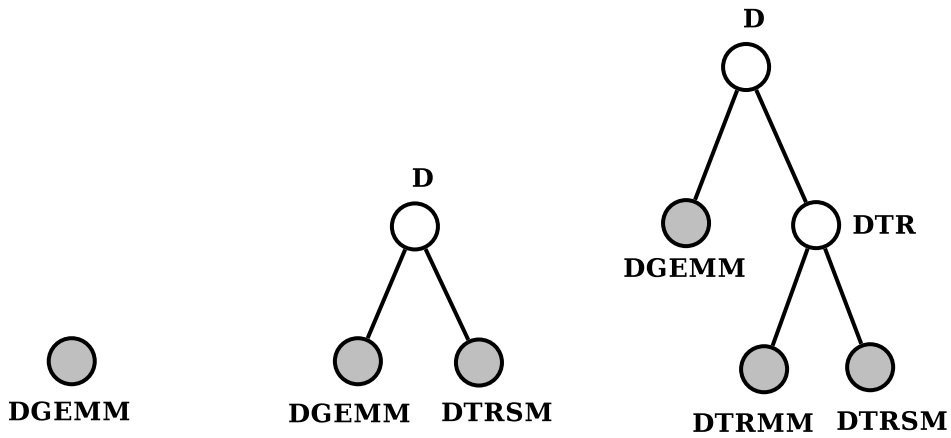

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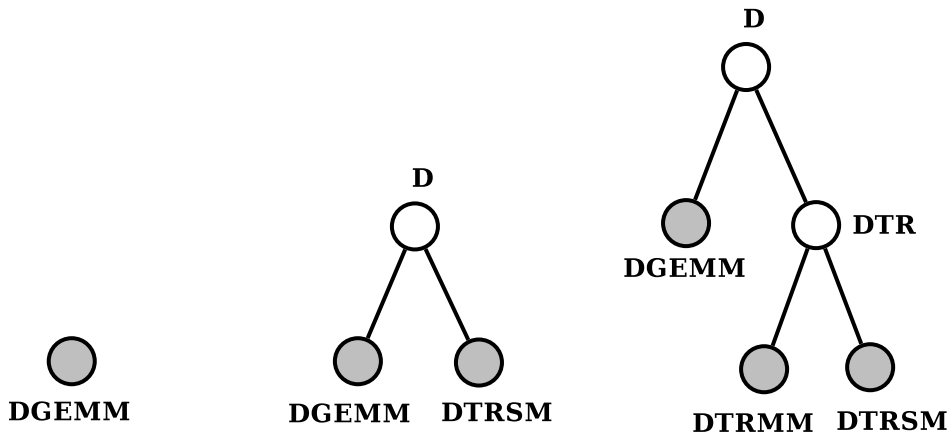

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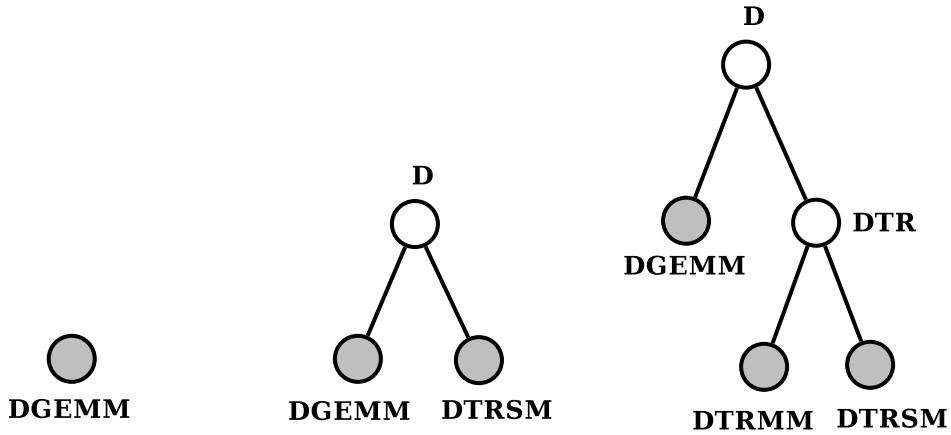
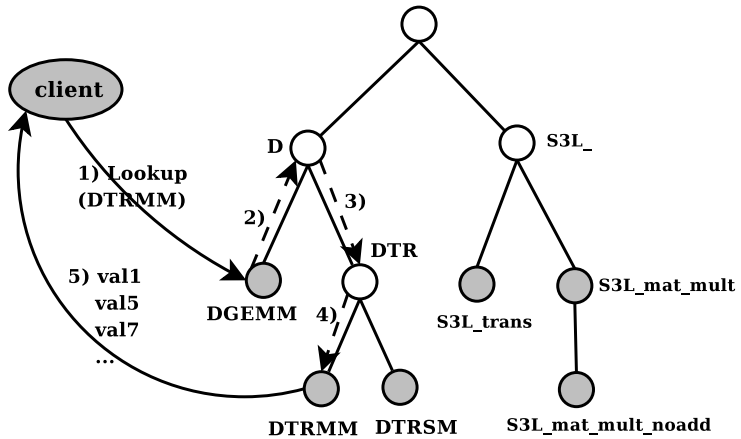


Lookup

- Exact match
- Autocompetion
- Range queries



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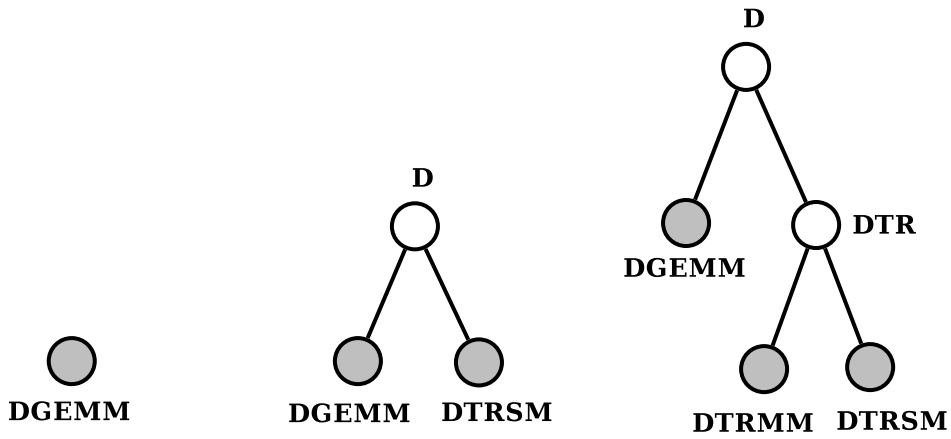

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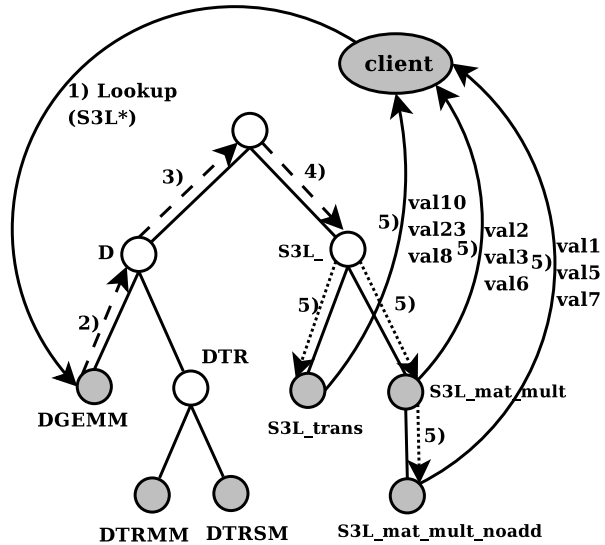

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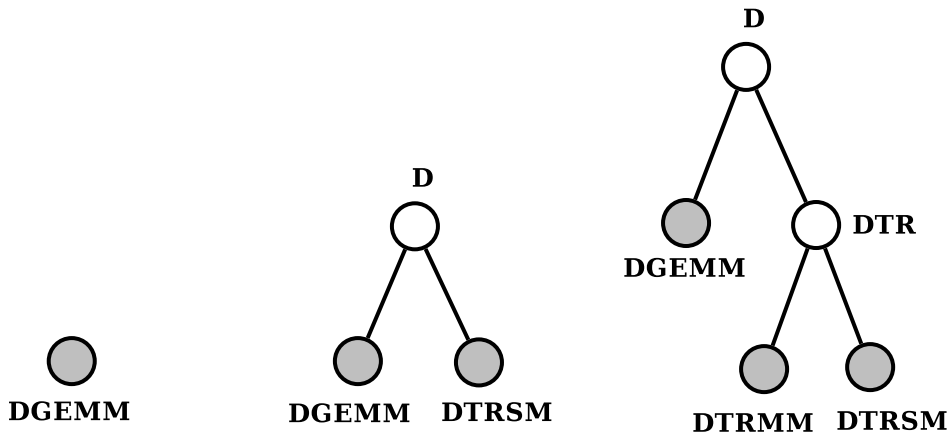

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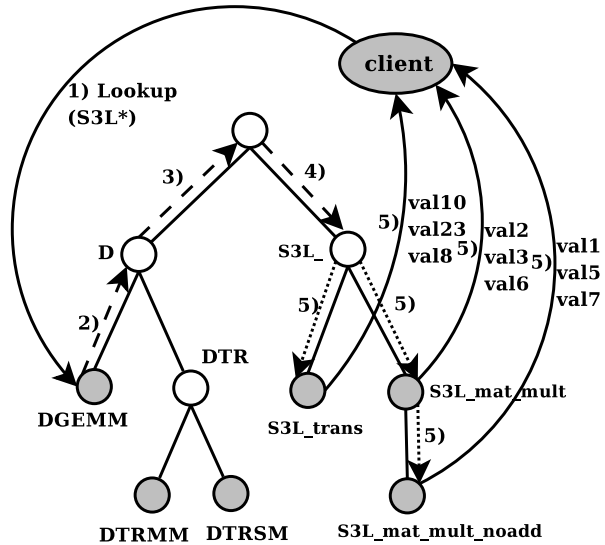

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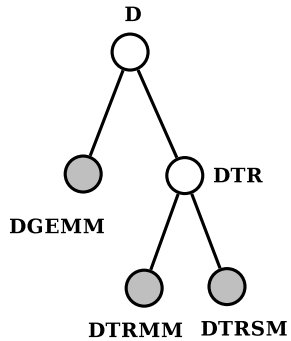
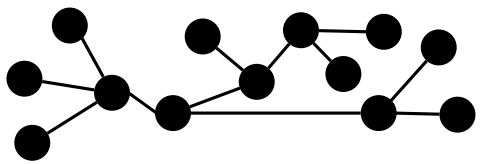
The Mapping Problem



- Associate a **Node** to a **Peer**
- An underlying DHT



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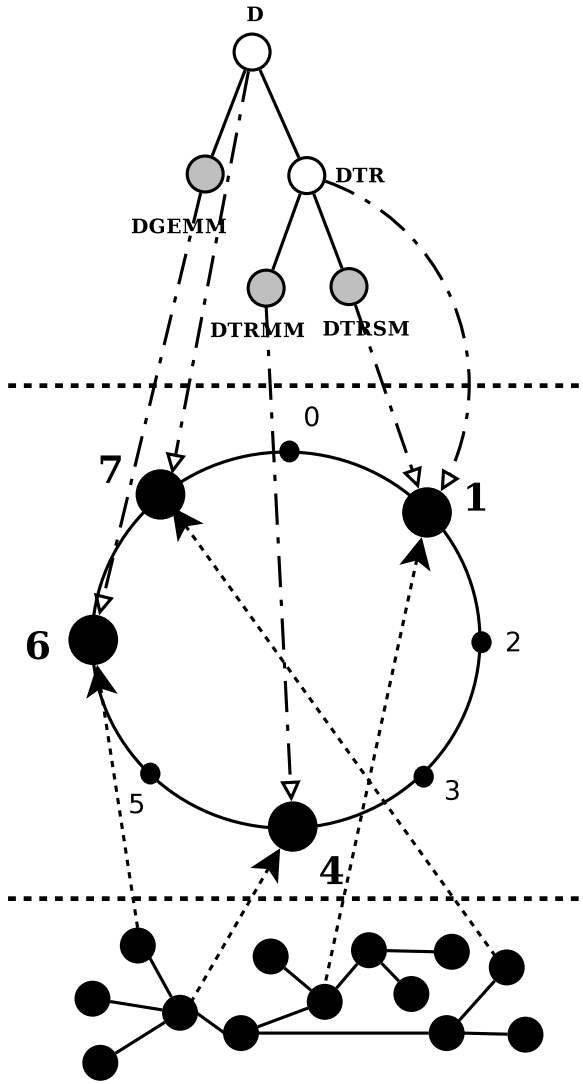
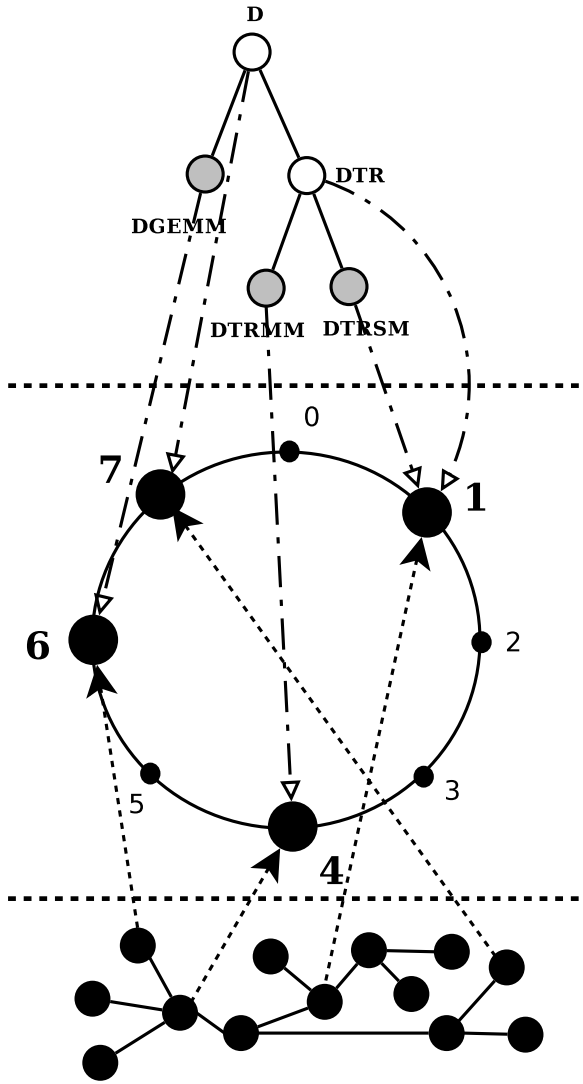


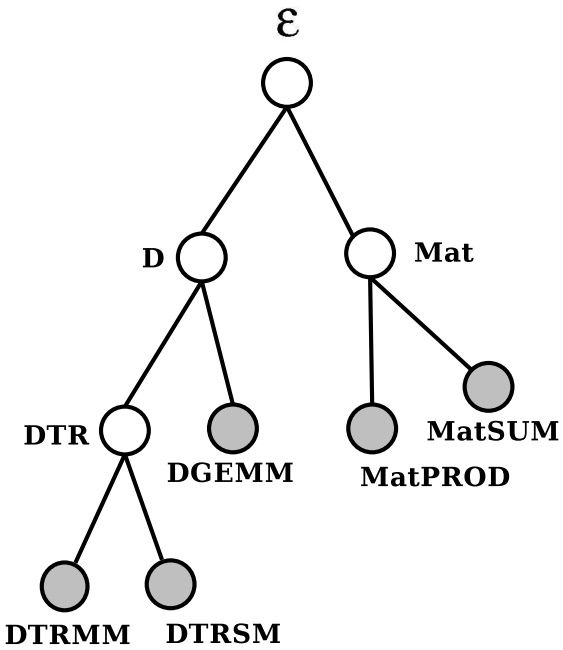
The Mapping Problem

Drawbacks

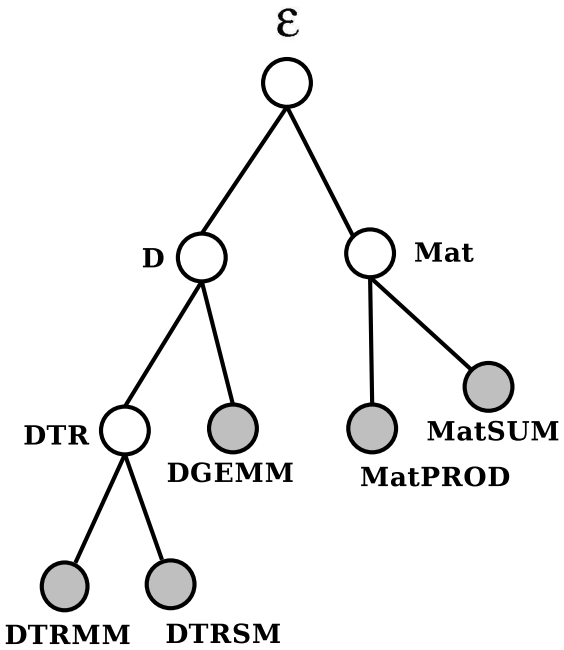
Need for a DHT

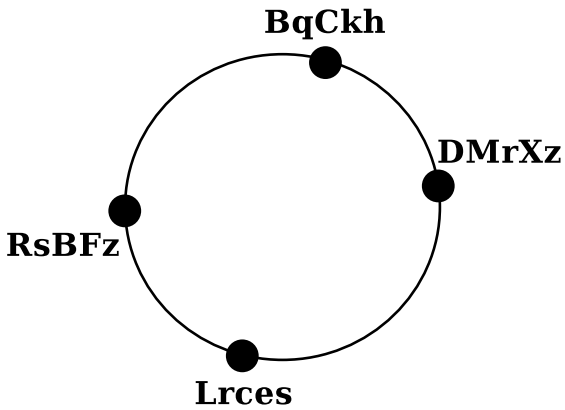
- Costly
- Random mapping (No clustering)





- Build a ring over peers
- Each peer maintains at least one node
- Map using **consistent hashing**
- Clustering





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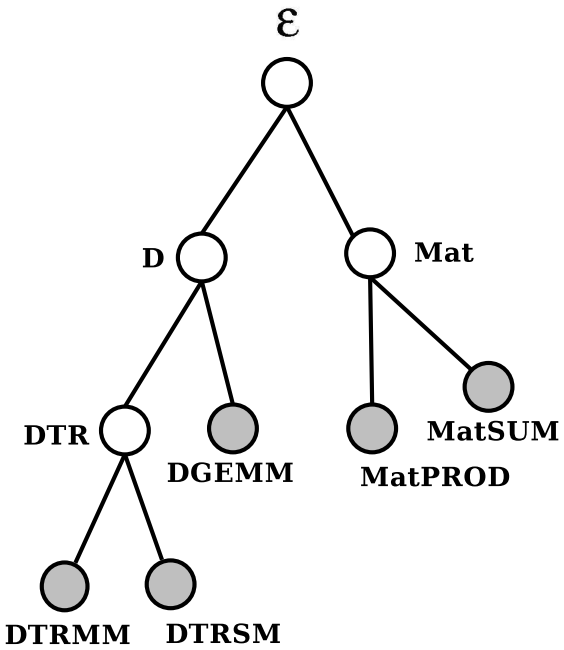

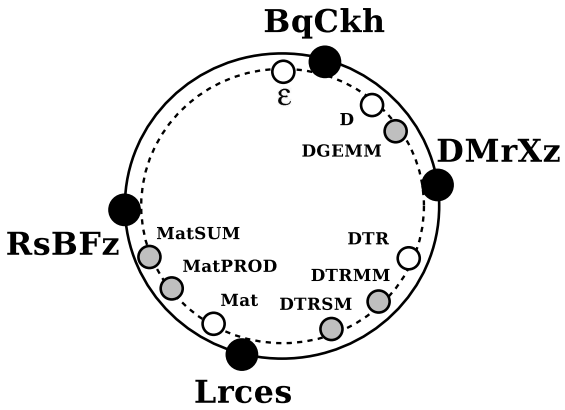

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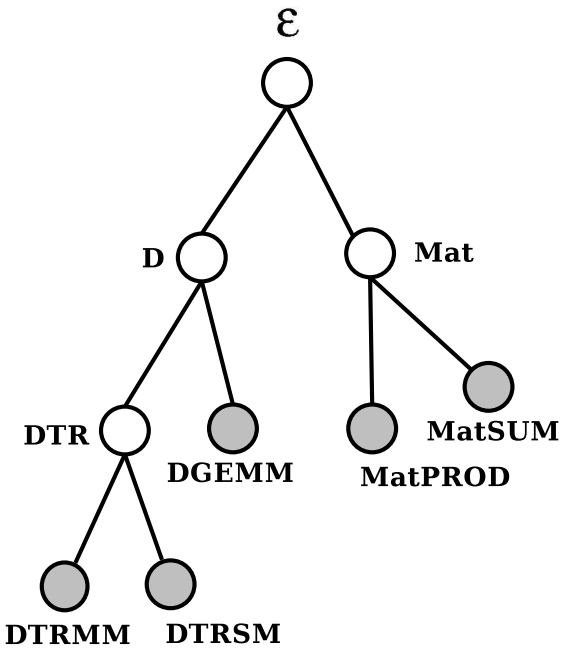

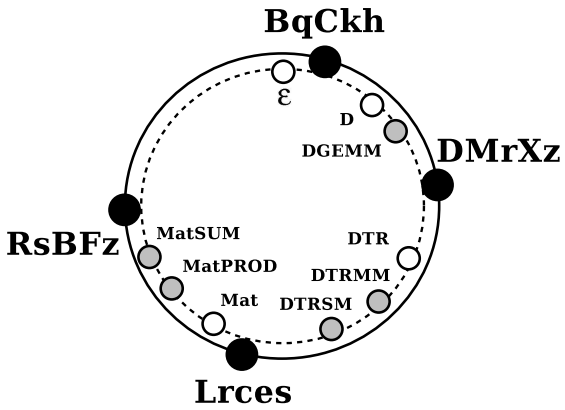

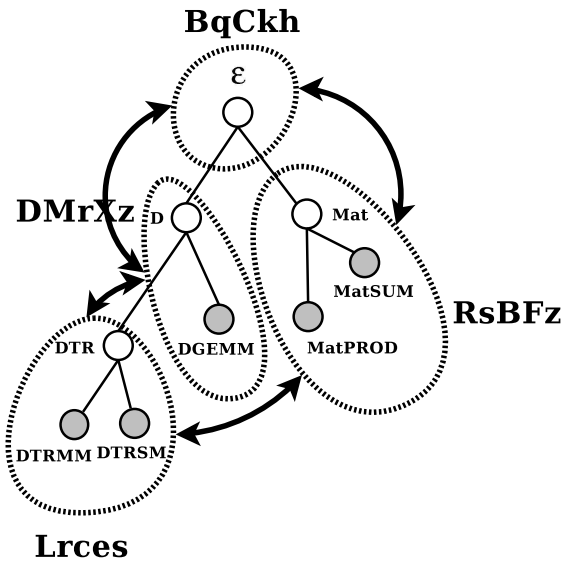

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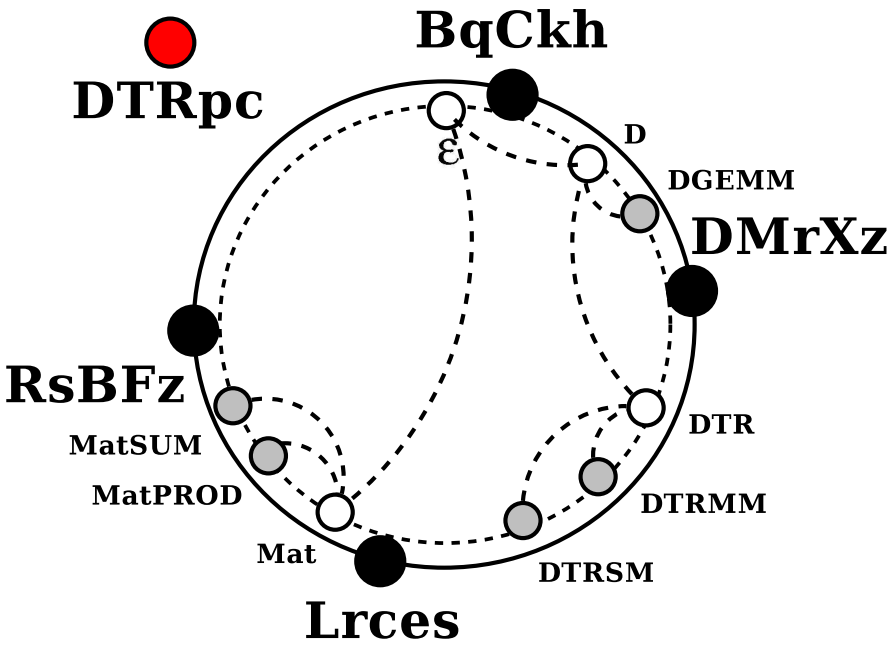
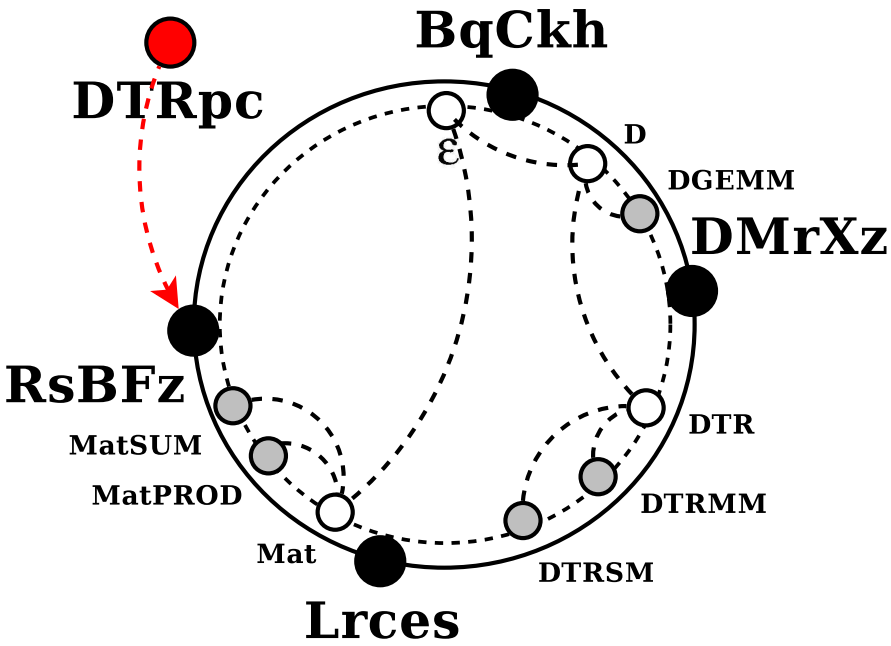
Insertion of a New Peer



Join Algorithm

1. Random contact peer
2. Initiating the tree routing
3. Routing in the tree
4. Successor of P is P_n or $succ(P_n)$

Insertion of a New Peer



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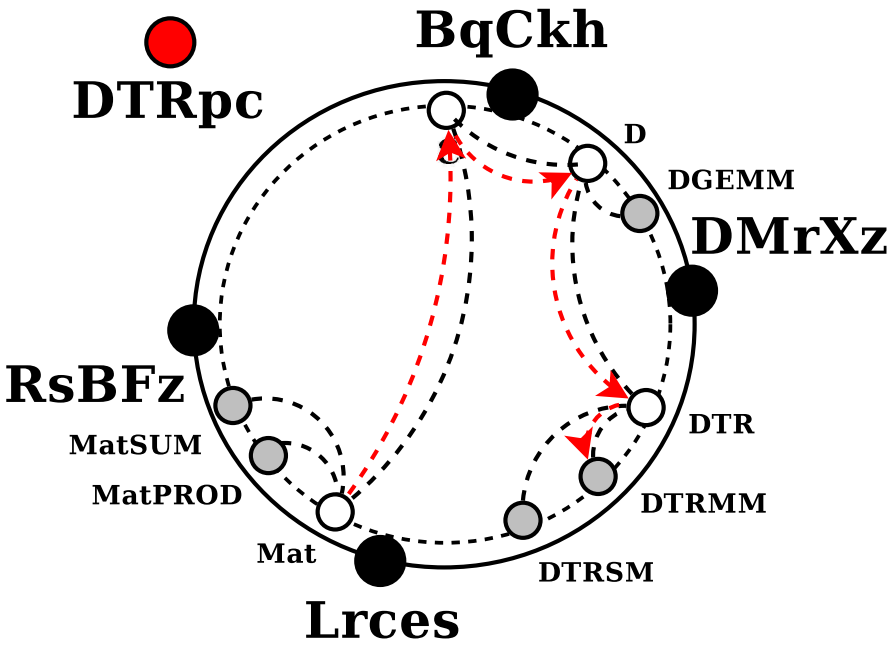

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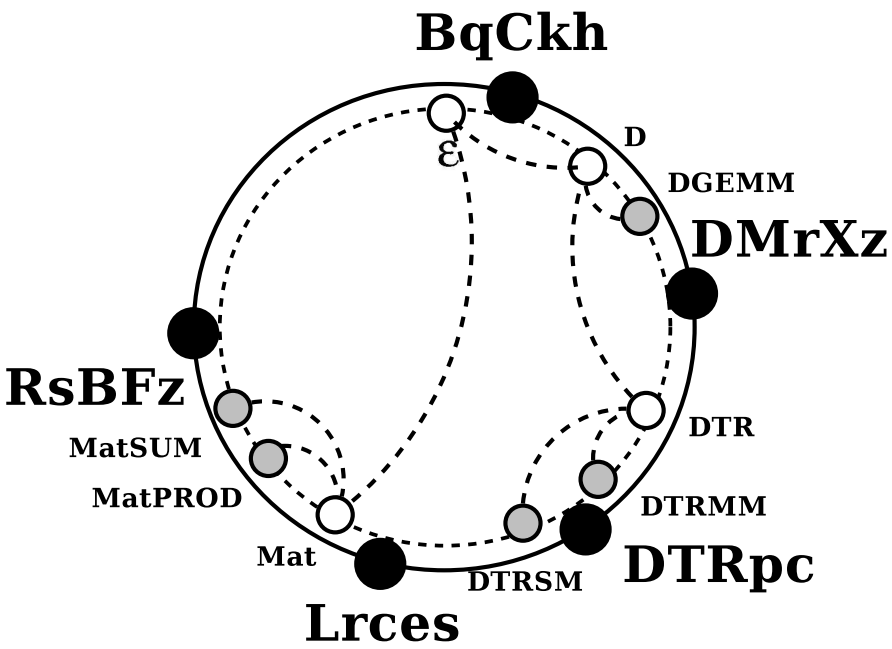

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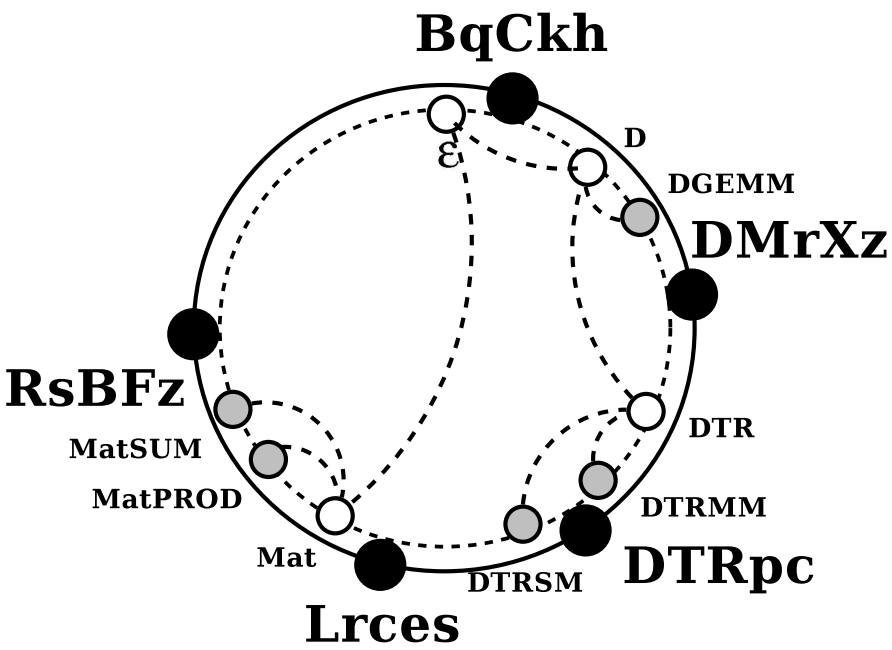

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Join Complexities

$O(Trie\ complexities)$

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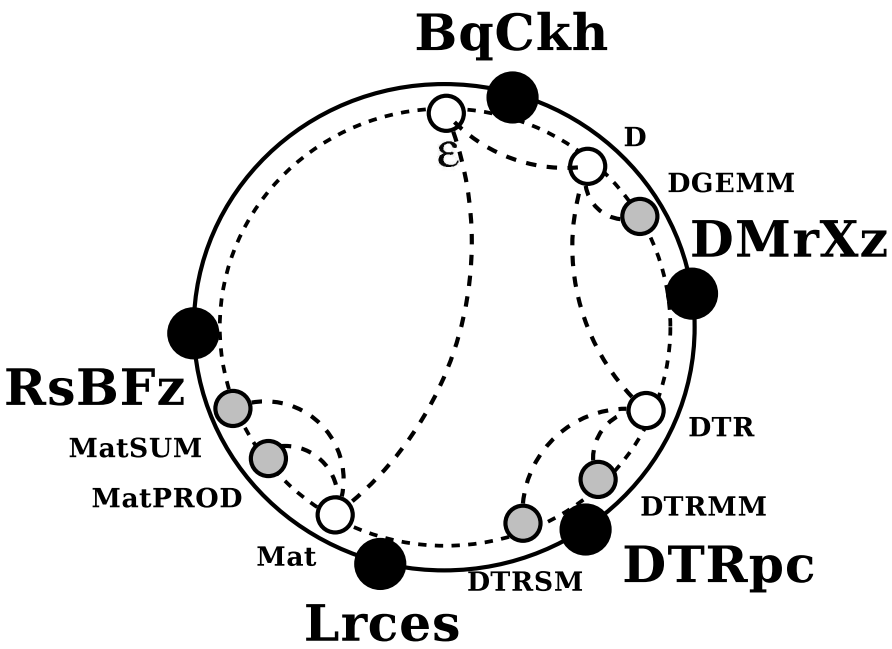

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Join Complexities

$O(Trie\ complexities)$

Load balancing

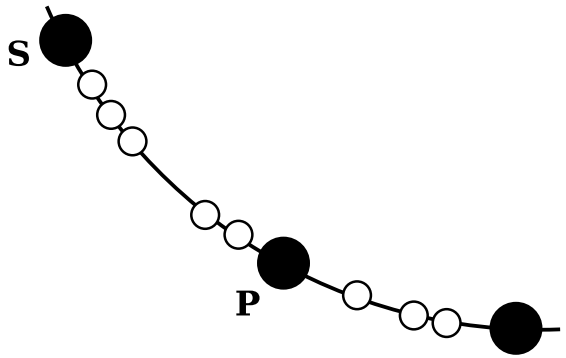
- Depth of nodes
- Popularity of services
- Capacity of peers

Load balancing heuristics - related work (DHTs)

Each peer is assigned a set of *items*

- Karger and Ruhl, 2001
  - Periodic random item balancing
  - Homogeneity of peer capacities
- Godfrey *et al.*, 2003
  - Periodic item redistribution
  - Semi-centralized
- Ledlie and Seltzer, 2005
  - Chooses the best location for a joining peer among k
  - Heterogeneity of peer capacities and data popularity

A novel heuristic : **Max Local Throughput**



(a)

End of period τ
S get load information
from P

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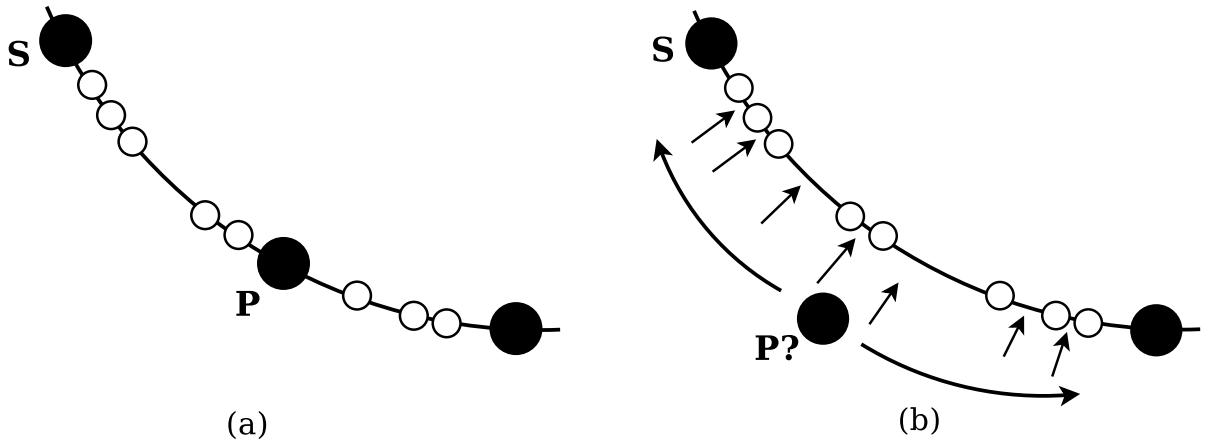

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Search for a new locally optimal distribution

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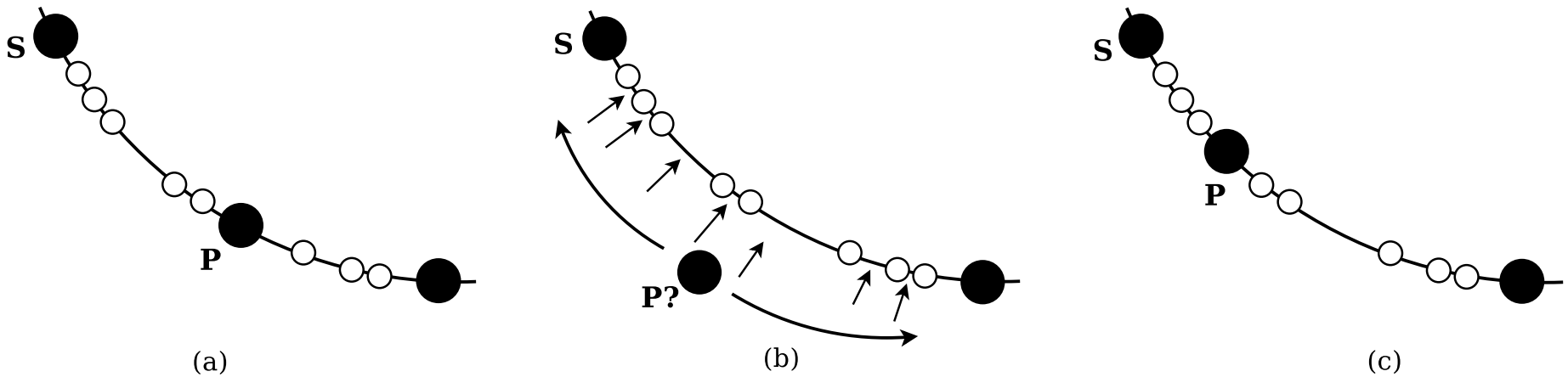

End of period τ
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Search for a new locally optimal distribution

Starting the next period $\tau + 1$

A novel heuristic : **Max Local Throughput**

- At the end of period τ
- Two adjacent peers S and P with capacity C_S and C_P
- ν_S^τ and ν_P^τ the sets of nodes currently managed by S and P
- $L_S^\tau = \sum_{n \in \nu_S^\tau} l_n$
- $L_P^\tau = \sum_{n \in \nu_P^\tau} l_n$
- $T_{S,P}^\tau = min(L_S^\tau, C_S) + min(L_P^\tau, C_P)$
- Maximize the throughput of $\tau + 1$ based on information of τ
- Find $\nu_S^{\tau+1}$ and $\nu_P^{\tau+1}$ that maximizes $T_{S,P}^{\tau+1}$.

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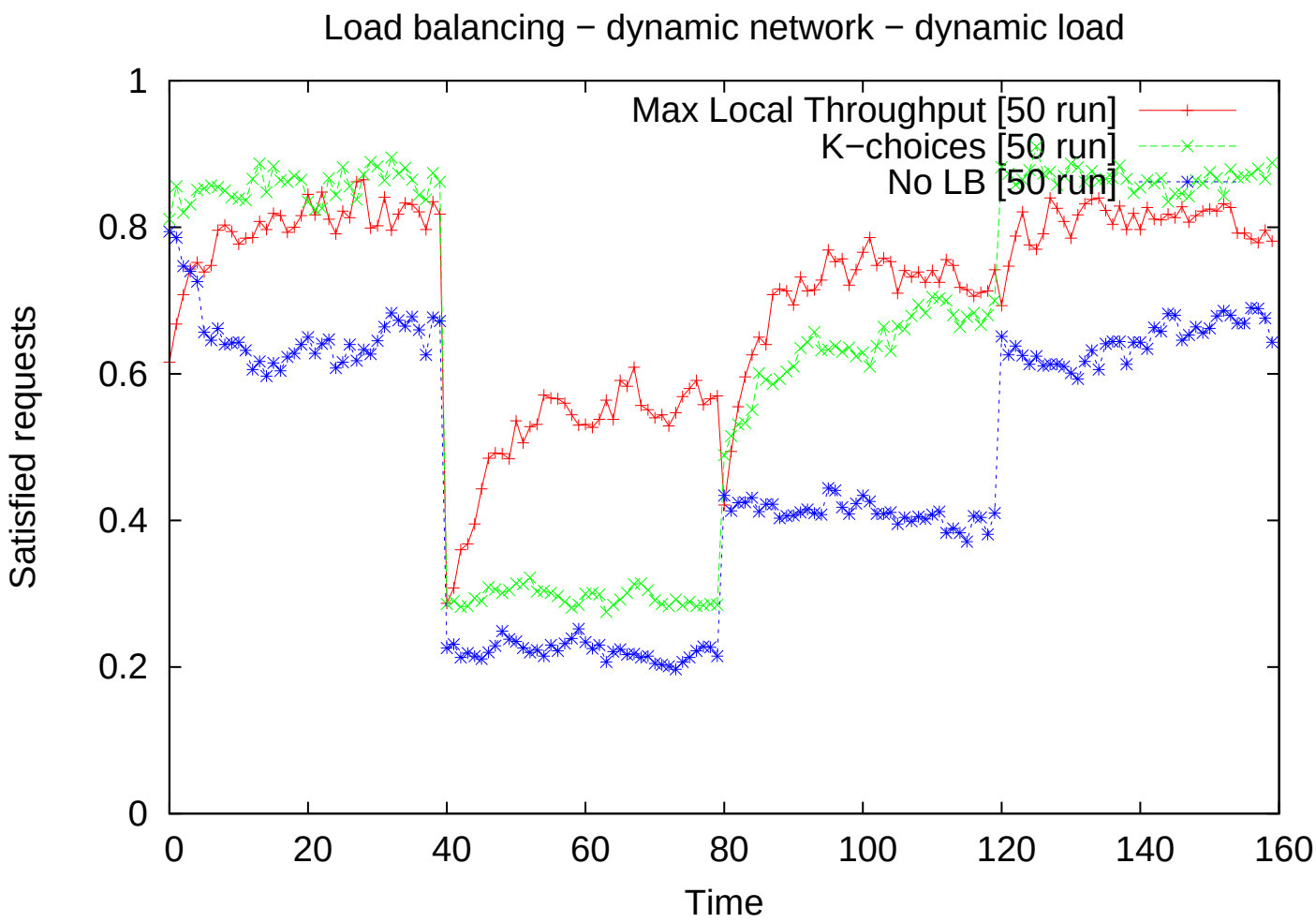
Simulation results

Load	Stable network		Dynamic network	
	Max local th.	K-choices	Max local th.	K-choices
5%	39,62%	38,58%	18.25%	32,47%
10%	103,41%	58,95%	46,16%	51,00%
16%	147,07%	64,97%	65,90%	59,11%
24%	165,25%	59,27%	71,26%	60,01%
40%	206,90%	68,16%	97,71%	67,18%
80%	230,51%	76,99%	90,59%	71,93%

Simulation results



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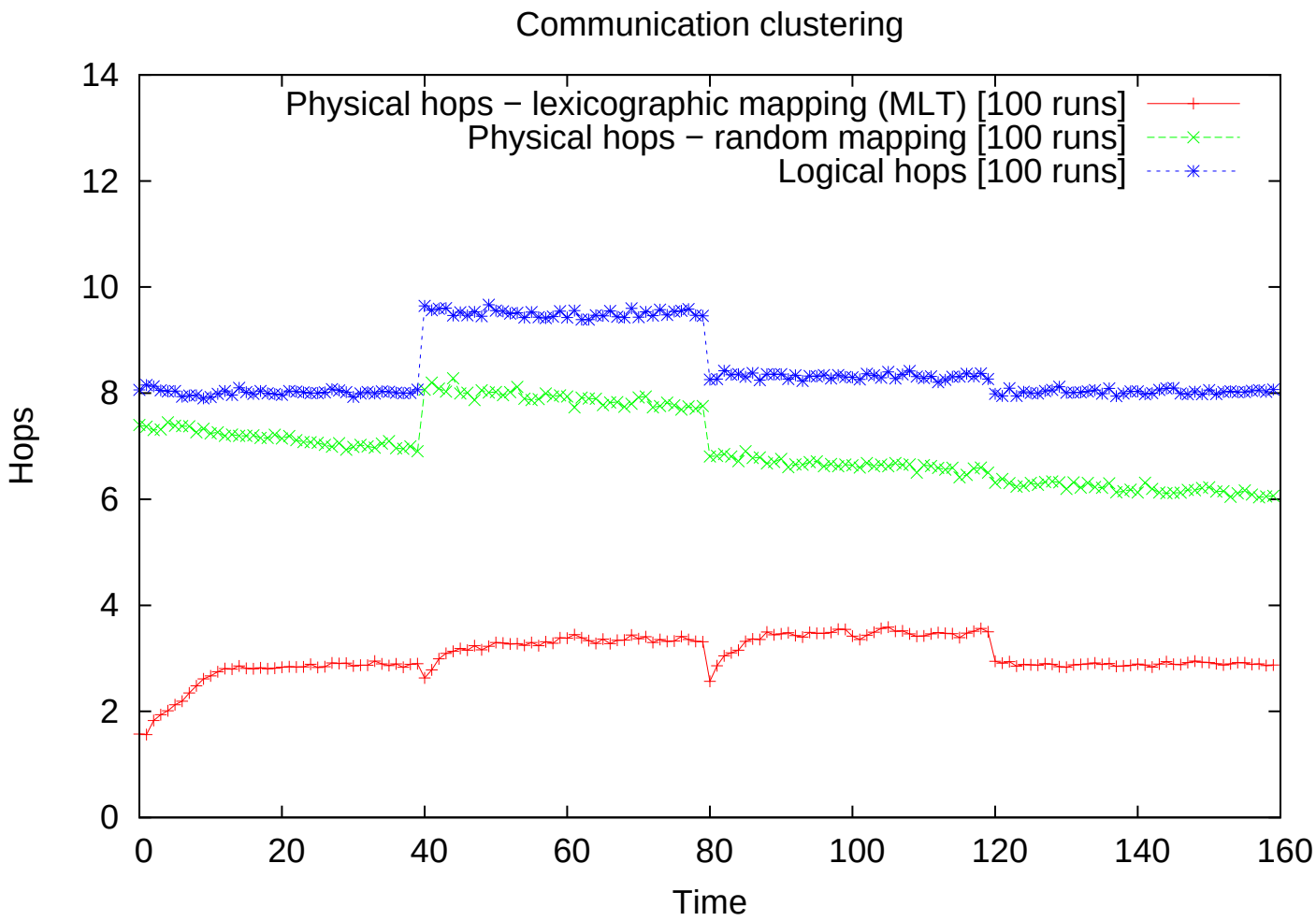

Outline

1. DLPT : a Trie-Based Solution
2. Mapping & Load Balancing
   - Protocol
   - Load Balancing
   - Simulation
3. Fault-tolerance
   - Snap-Stabilizing PGCP Tree (State Model)
   - Self-Stabilizing PGCP Tree (Message-Passing Model)
4. Prototype Implementation
   - Design
   - Early Experiments
5. Summary & Open Problems

- Creation and maintenance of the tree
- Fault-tolerance
  - Usually, based on replication
    - Costly
    - Unable to recover after arbitrary transient failures
  - Best-effort ?

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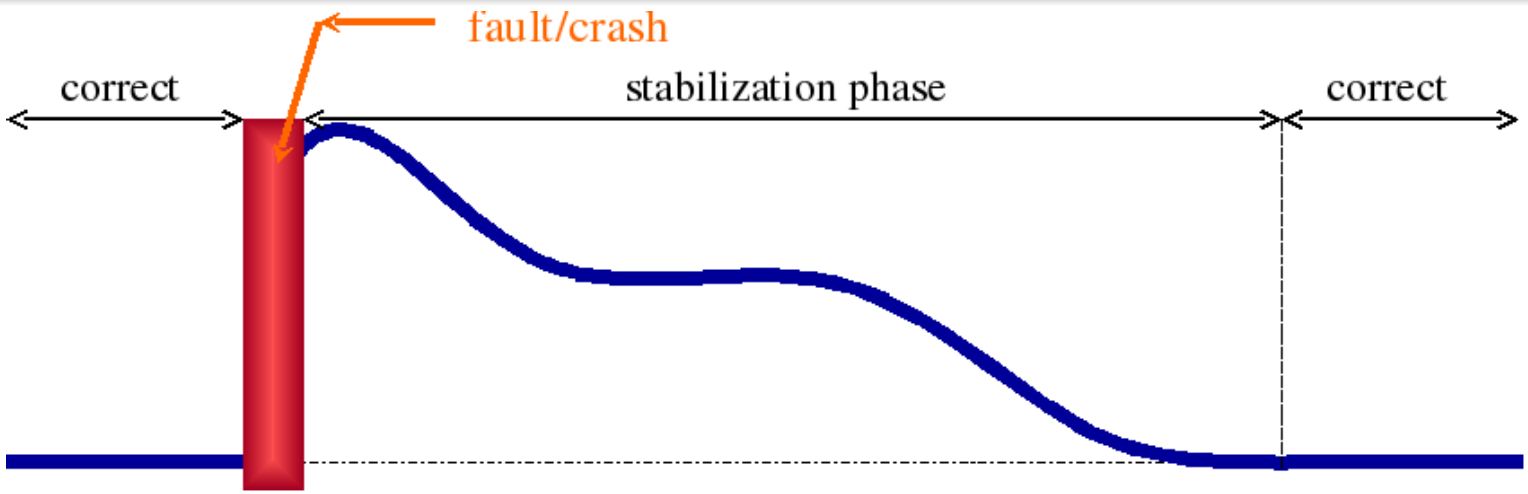
  - **Best-effort ?**

Self-Stabilization (Dijkstra, 74)

- General technique to tolerate transient faults
- Guaranteed to converge to the intended behavior
  - Regardless of the initial state of the system
  - In finite time



Architecture Model

Physical Network

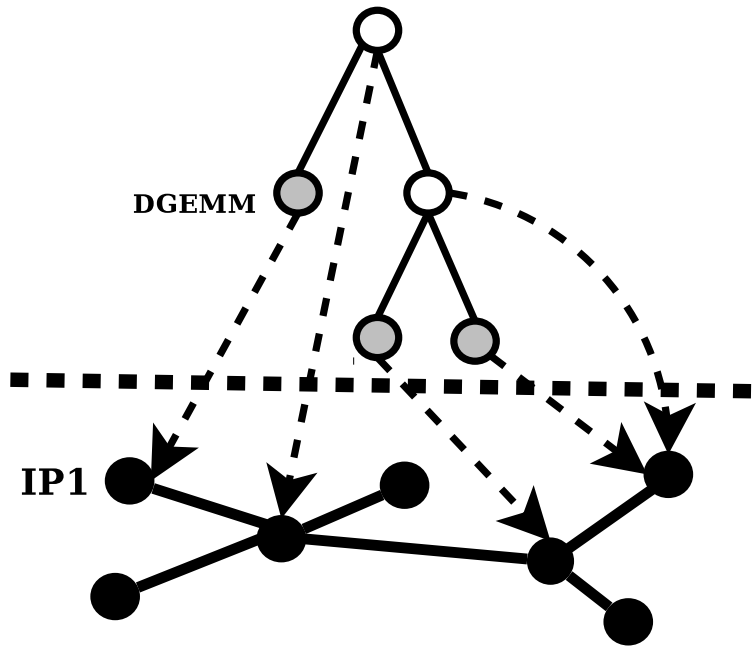
Basic entity : **peer** (processor)

- P_1 can communicate with P_2 if P_1 *knows* P_2.
- Runs some logical *nodes*

Logical Tree

Basic entity : (tree) **node**

- Distributed among peers
- Mapping details abstracted out
- Protocol run inside nodes



State Model

- Message exchanges modeled by the ability to read variables of other nodes (**Neighbors**)
- A node can only write its own variables

- The **state** of a node is defined by the values of its variables
- The **configuration** of the system is the product of the states

- Actions : $< guard > \rightarrow < statement >$
  - $< guard >$ bool. expr. of variables of p and its neighbors
  - $< statement >$
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- Distributed and unfair scheduler daemon

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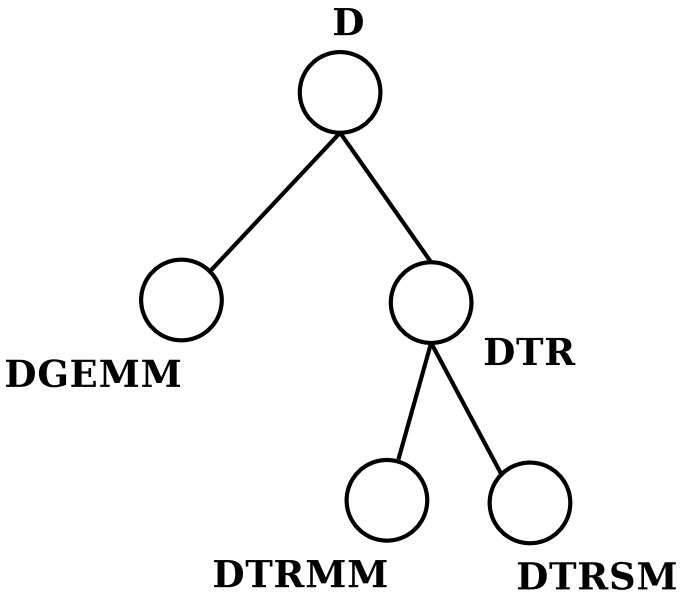
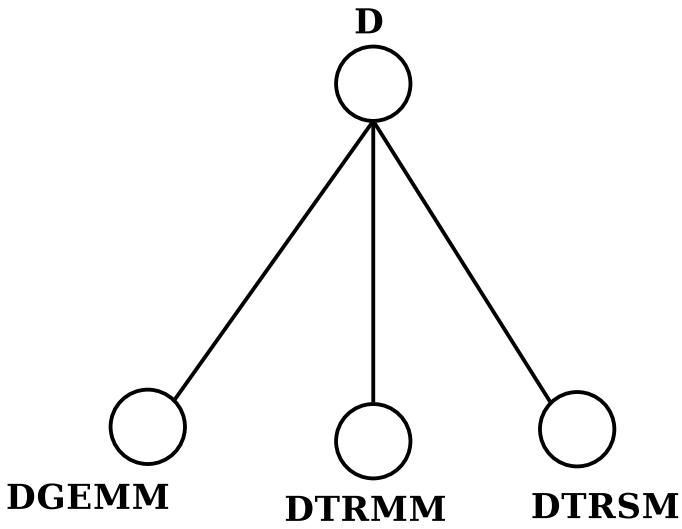
Snap-stabilization

Let P be a protocol designed to solve a task T. P is said **snap-stabilizing** if and only if, starting from any configuration, any execution e of P always satisfies the specification of T.

The Distributed Structures Maintained





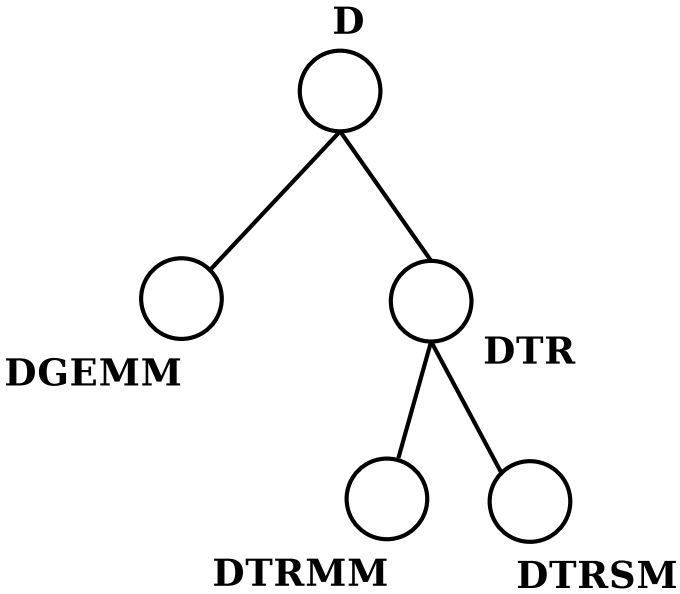
PGCP Tree

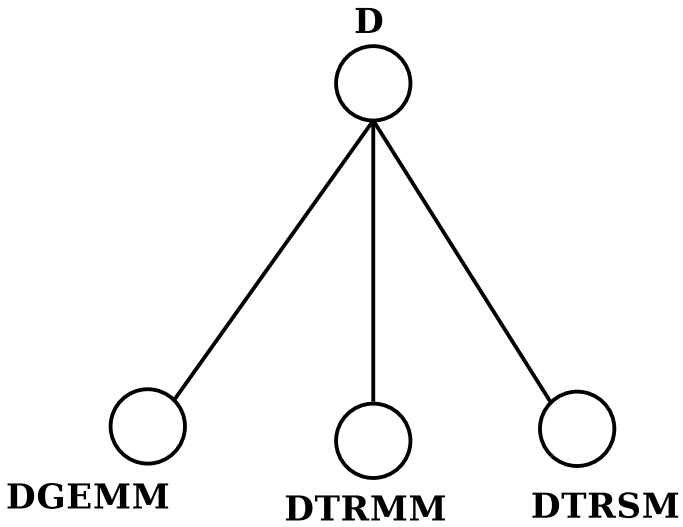
A labeled rooted tree s.t. each node label is the **PGCP** of any pair of its children labels.

Prefix Heap

A labeled rooted tree s.t. each node label is the **PGCP** of all its children labels.

The Distributed Structures Maintained





A Prefix Heap s.t. for each node p, every pair of children (q, r) :

$$\begin{cases} (1) & l_q \neq l_r \\ (2) & l_q(\text{resp. } l_r) \text{ is not a prefix of } l_r(\text{resp. } l_q) \\ (3) & |GCP(l_q, l_r)| = |l_p| \end{cases}$$

is a PGCP Tree.

Snap-stabilizing PGCP Tree construction

Topology Assumptions

The initial graph is a rooted connected tree.

Snap-stabilizing PGCP Tree

A protocol P is considered as a snap-stabilizing PGCP tree construction if and only if, any execution initiated by the root terminates in finite time and when the execution terminated, the tree is a PGCP tree.

The Protocol

Functions

- `newNode(lbl, st, chldn)`
- `destroy (p)`
- `heapify()` locally creates a heap
- `repair()` locally builds a PGCP Tree from a heap

Phases

- From the snap-stabilizing PIF [Bui, Datta, Petit, Villain - 99]
- **Broadcast** phase : top-down wave initiating the algorithm
- **Heapify** phase : down-top traversal building a prefix heap
- **Repair** phase : final top-down wave building a PGCP tree

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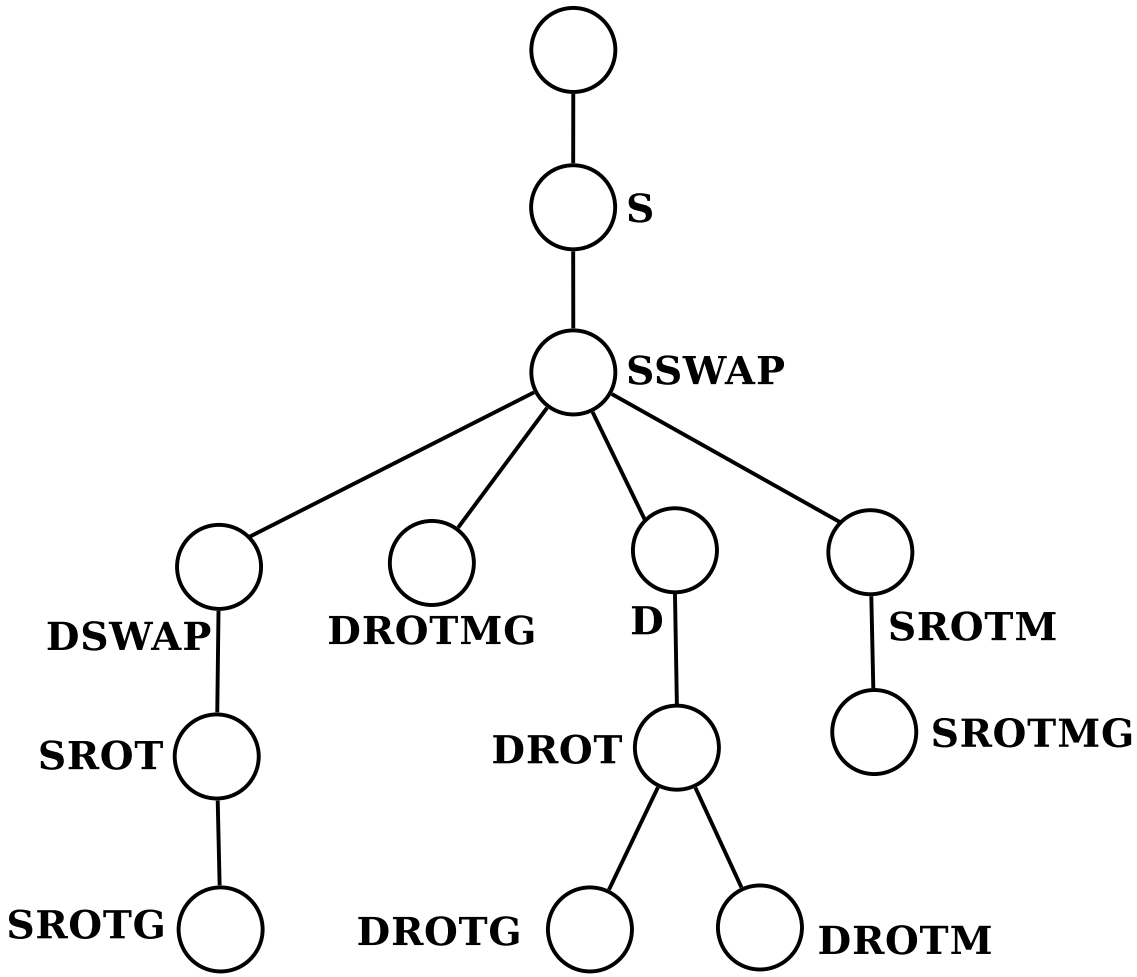
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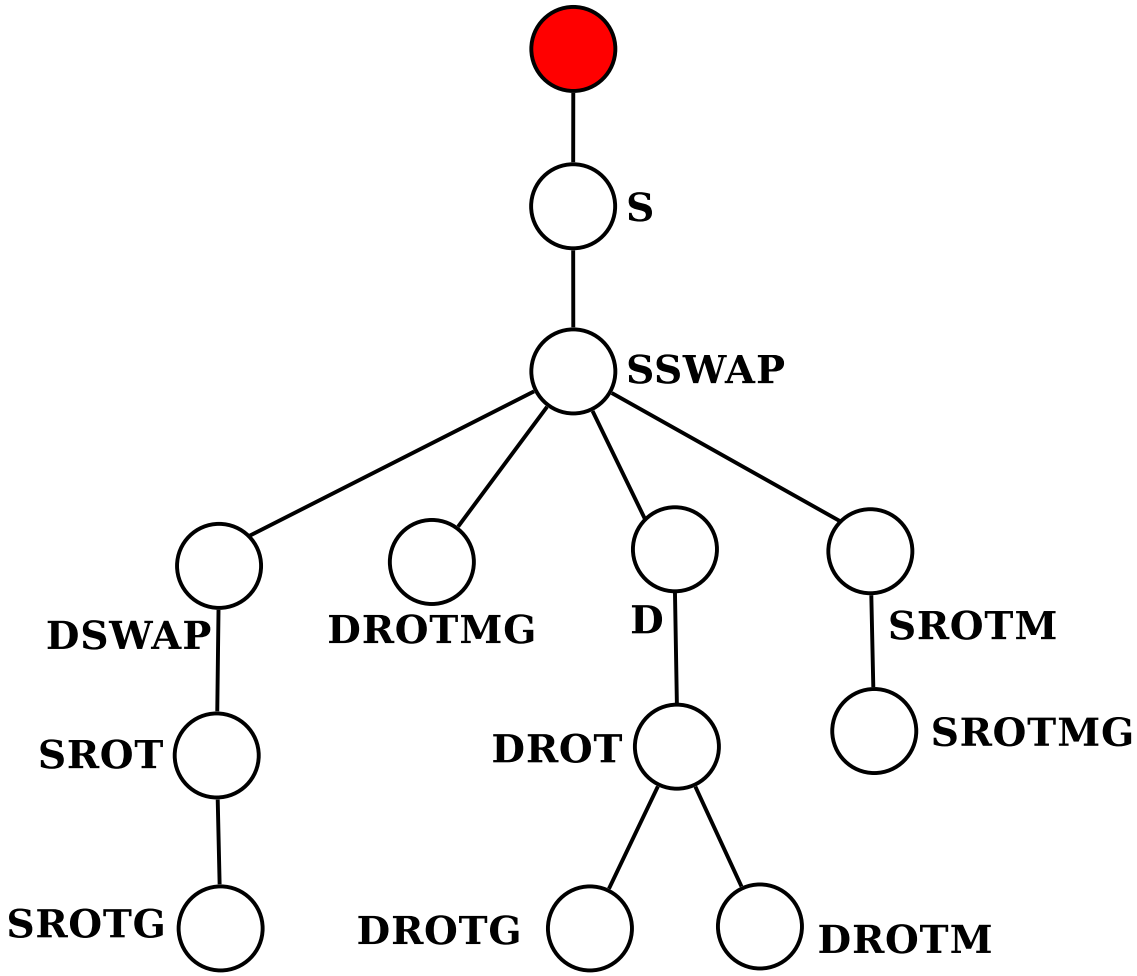
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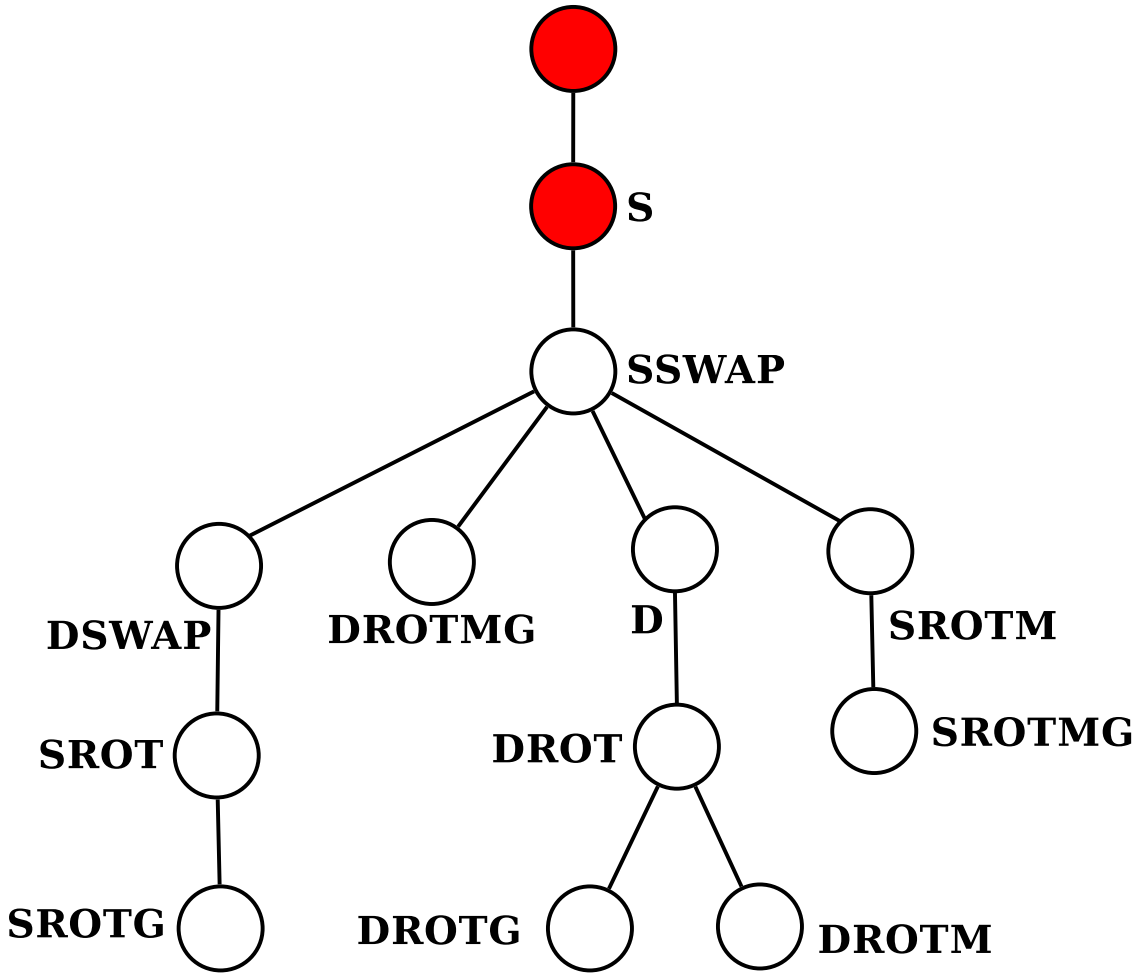
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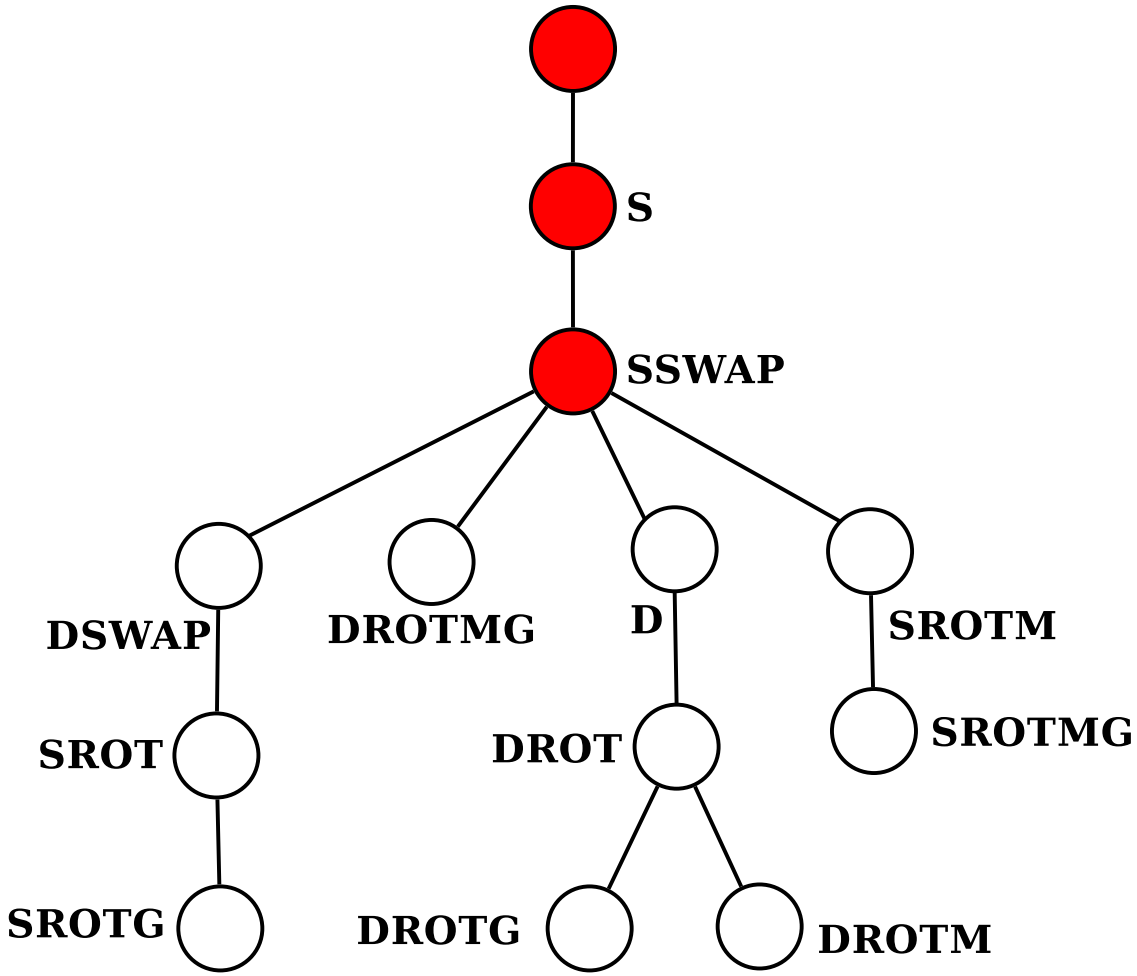
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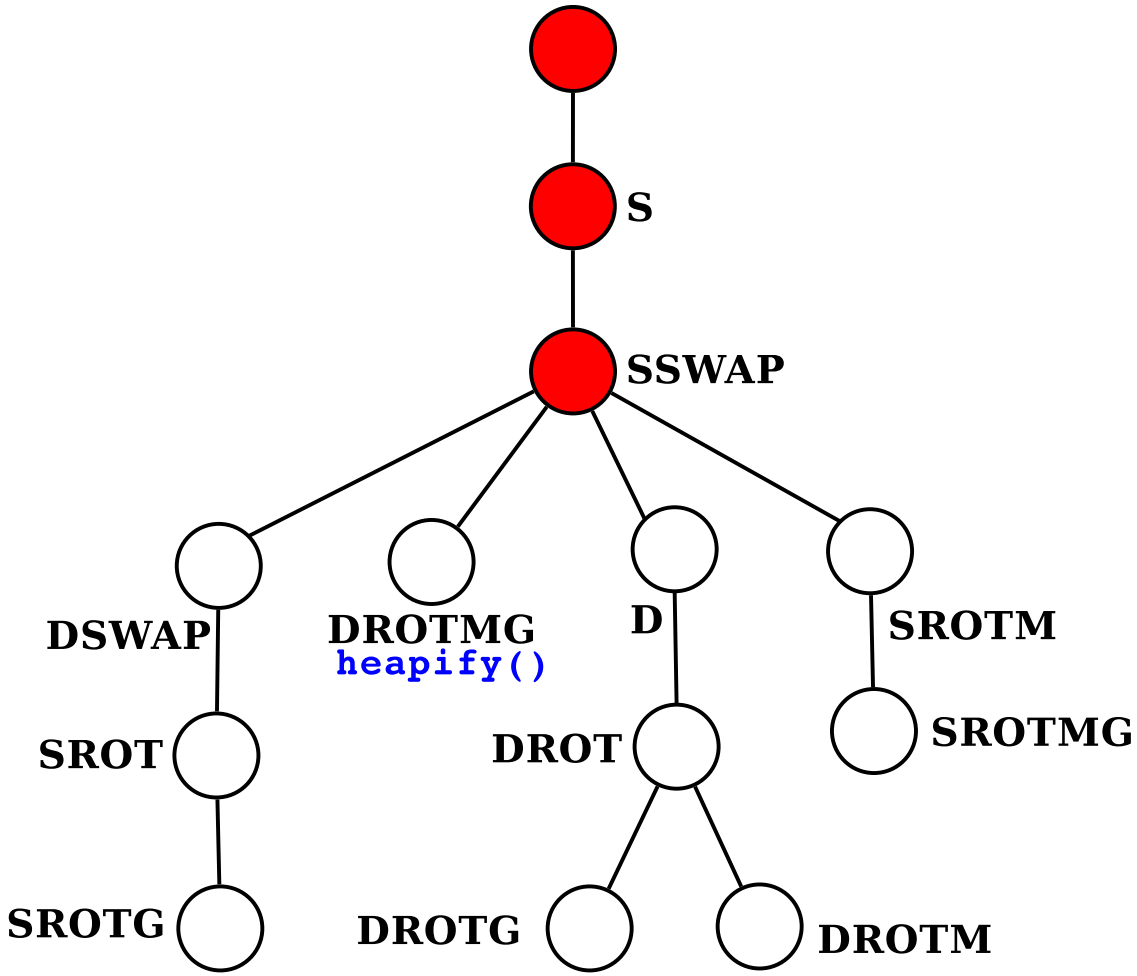
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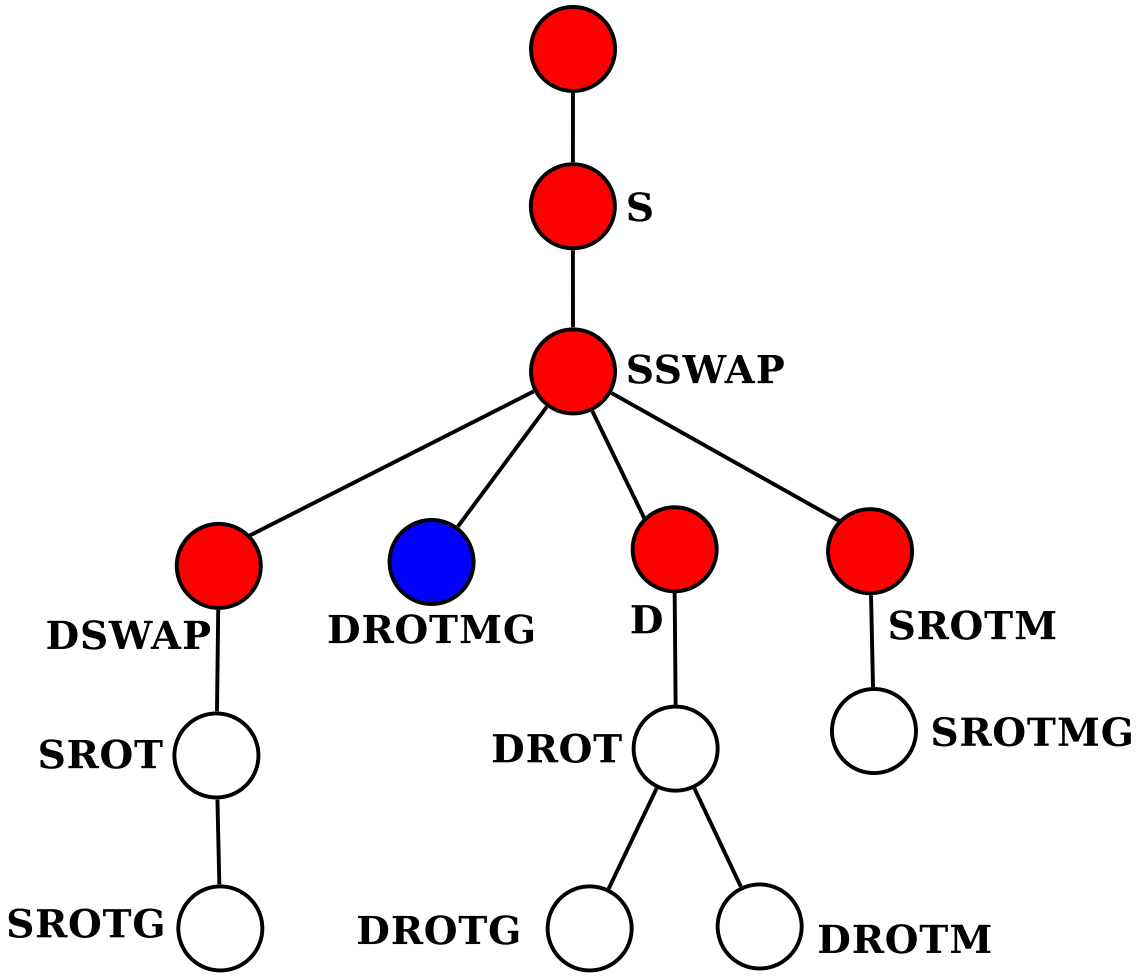
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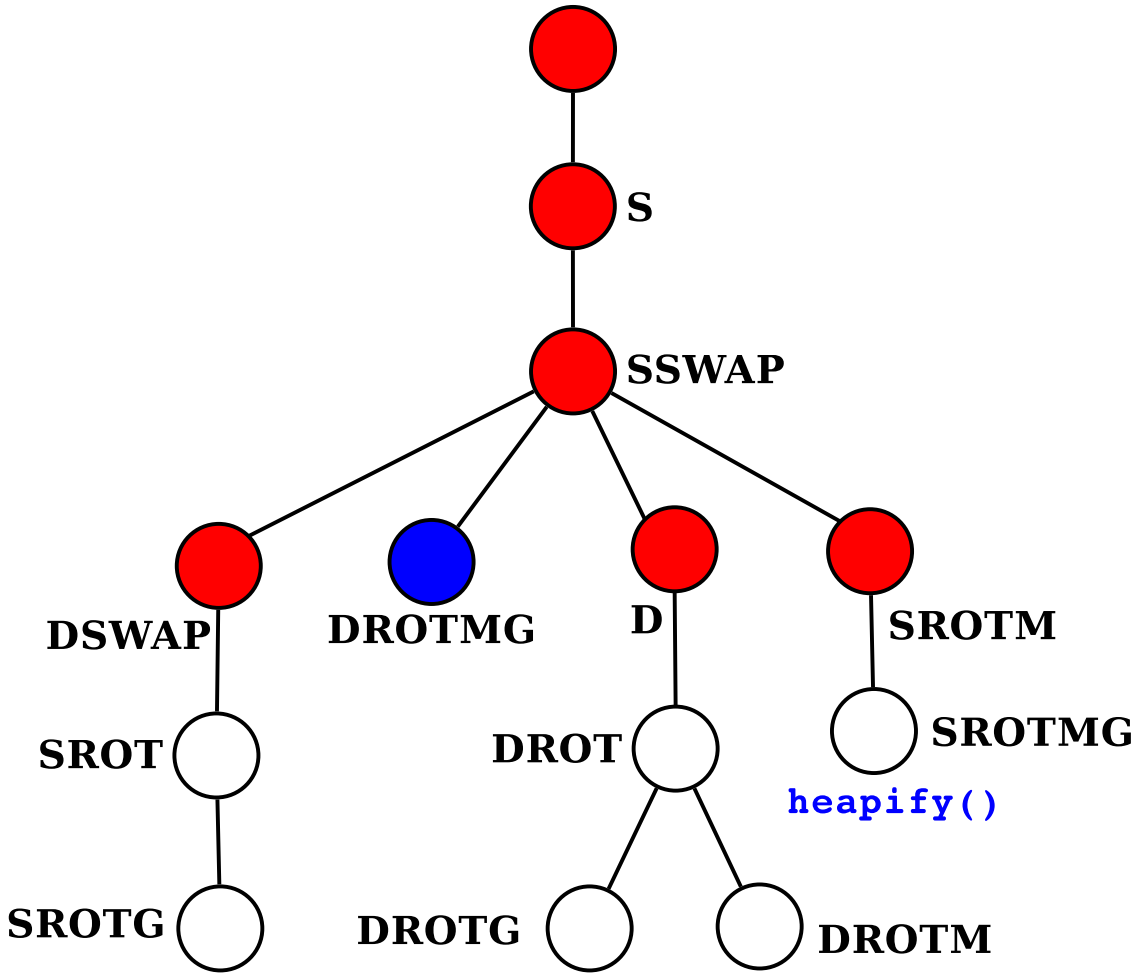
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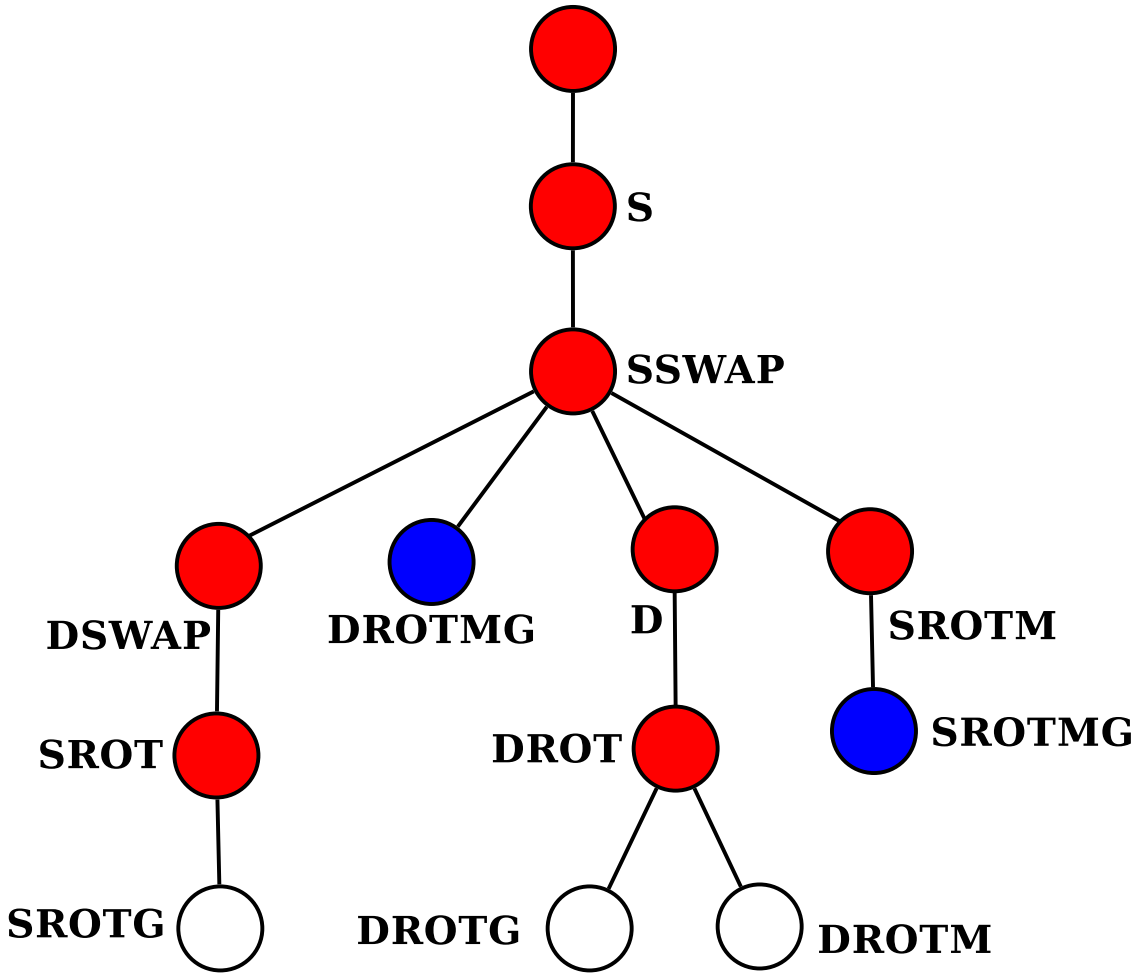
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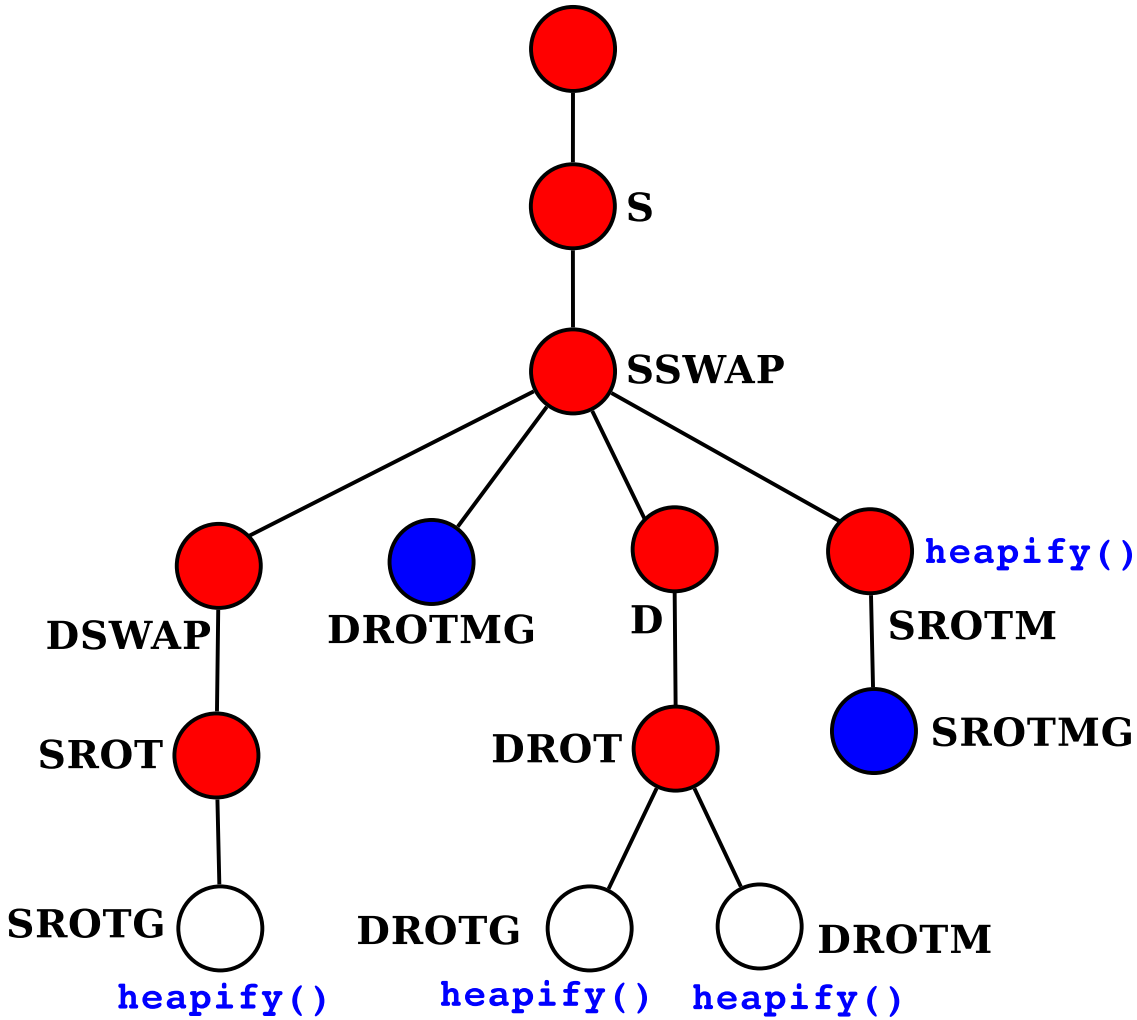
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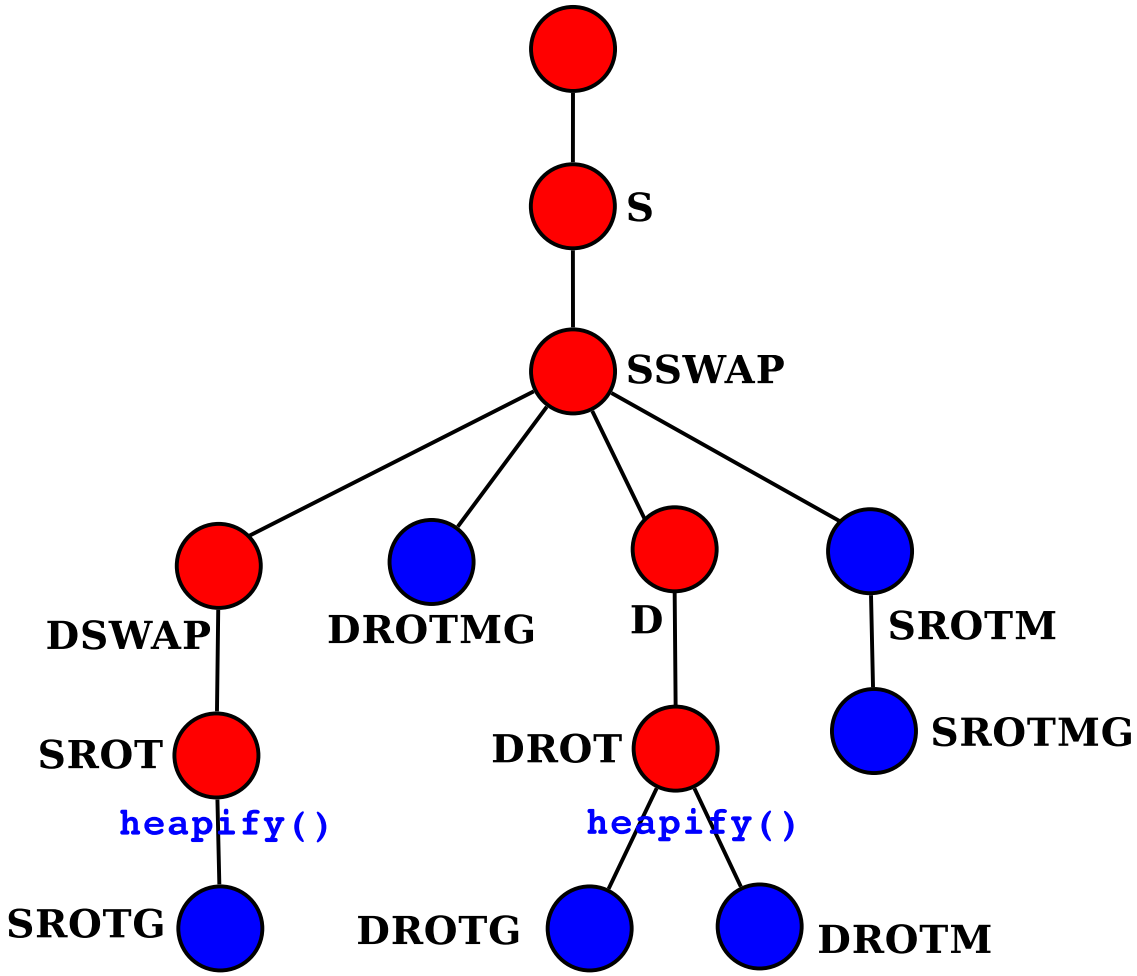
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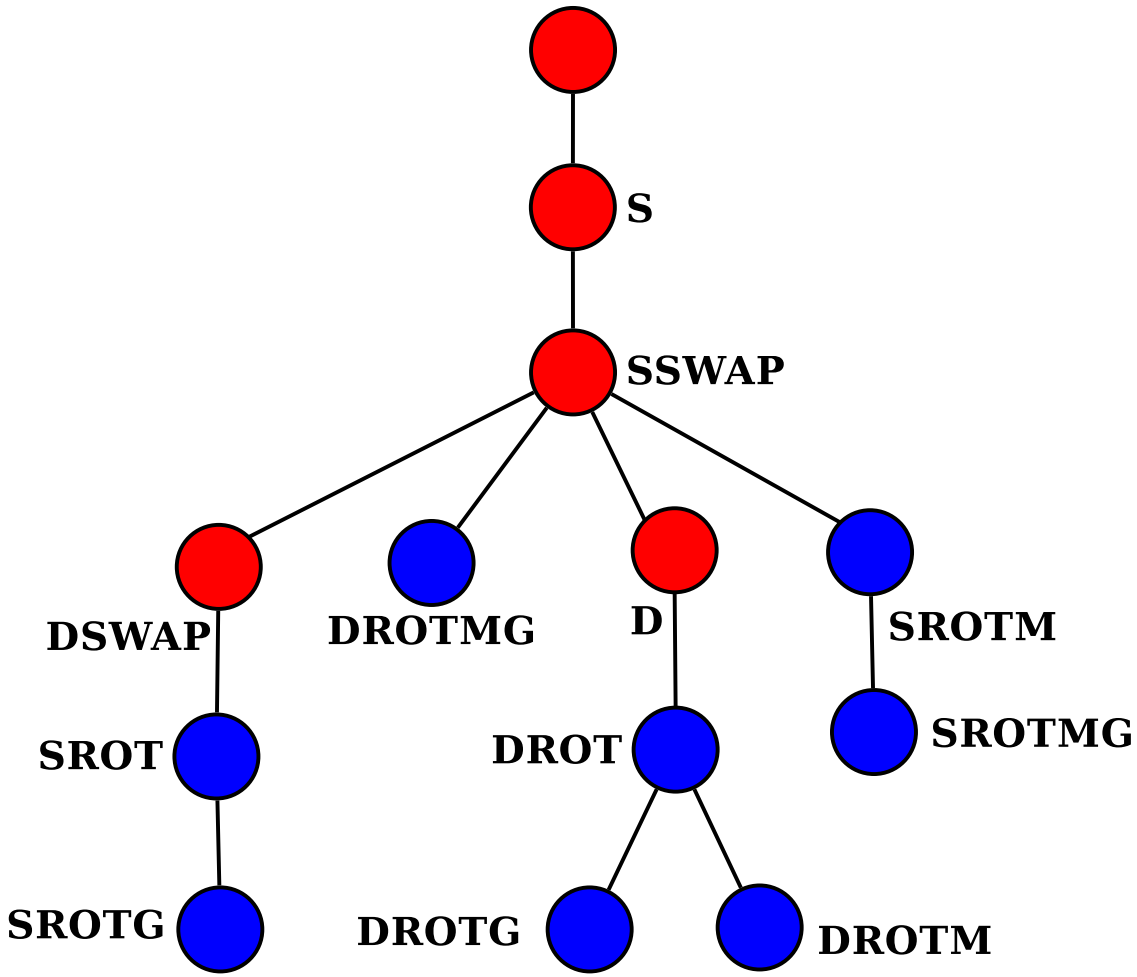
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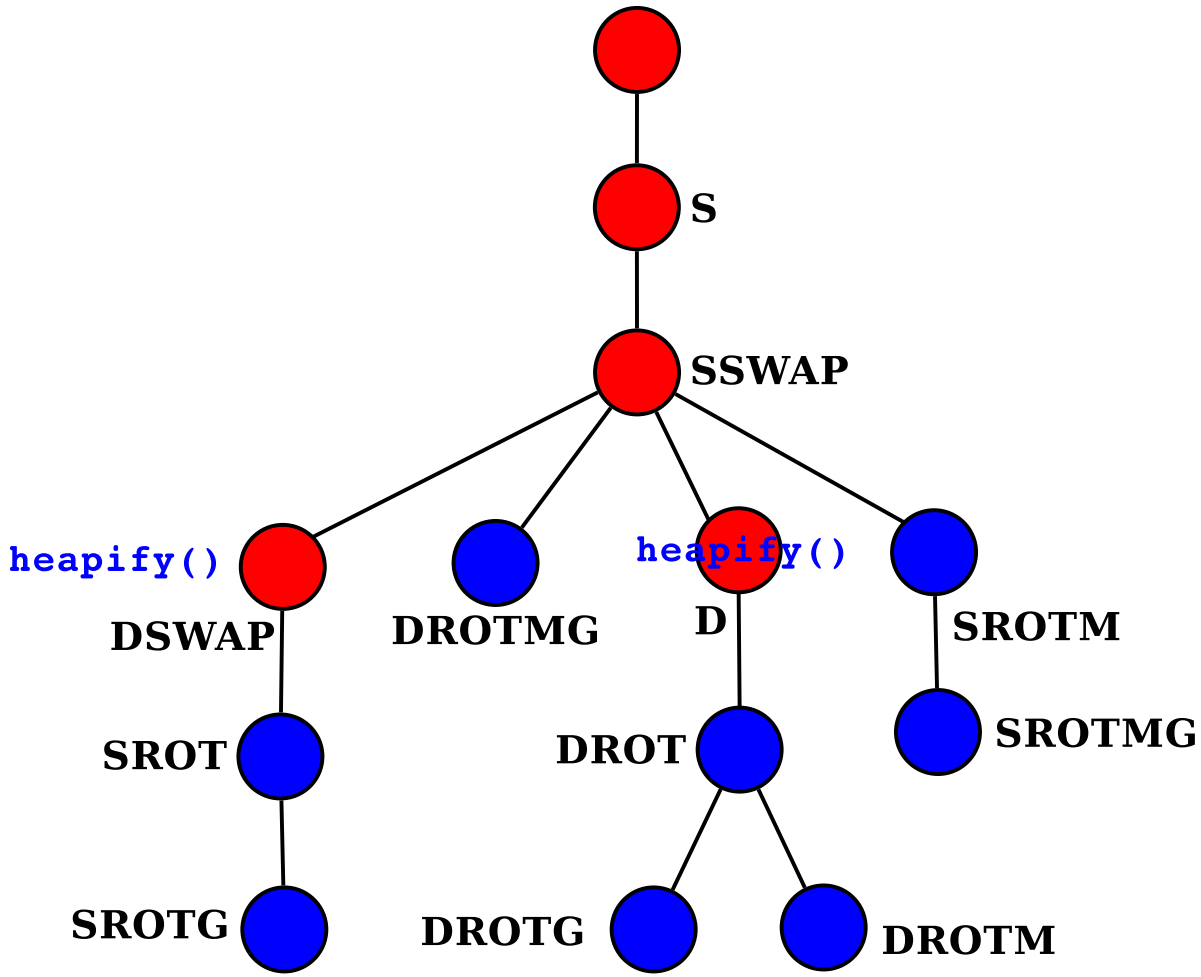
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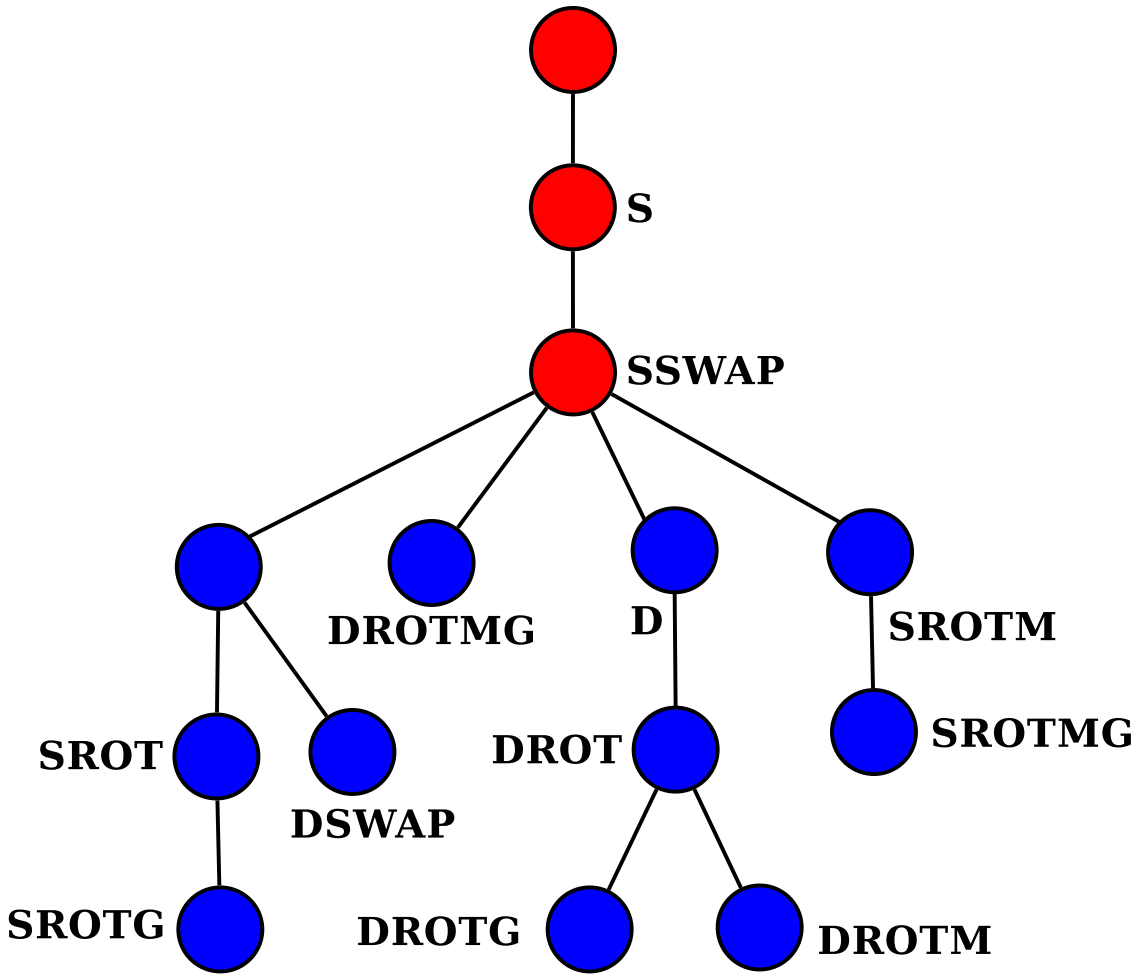
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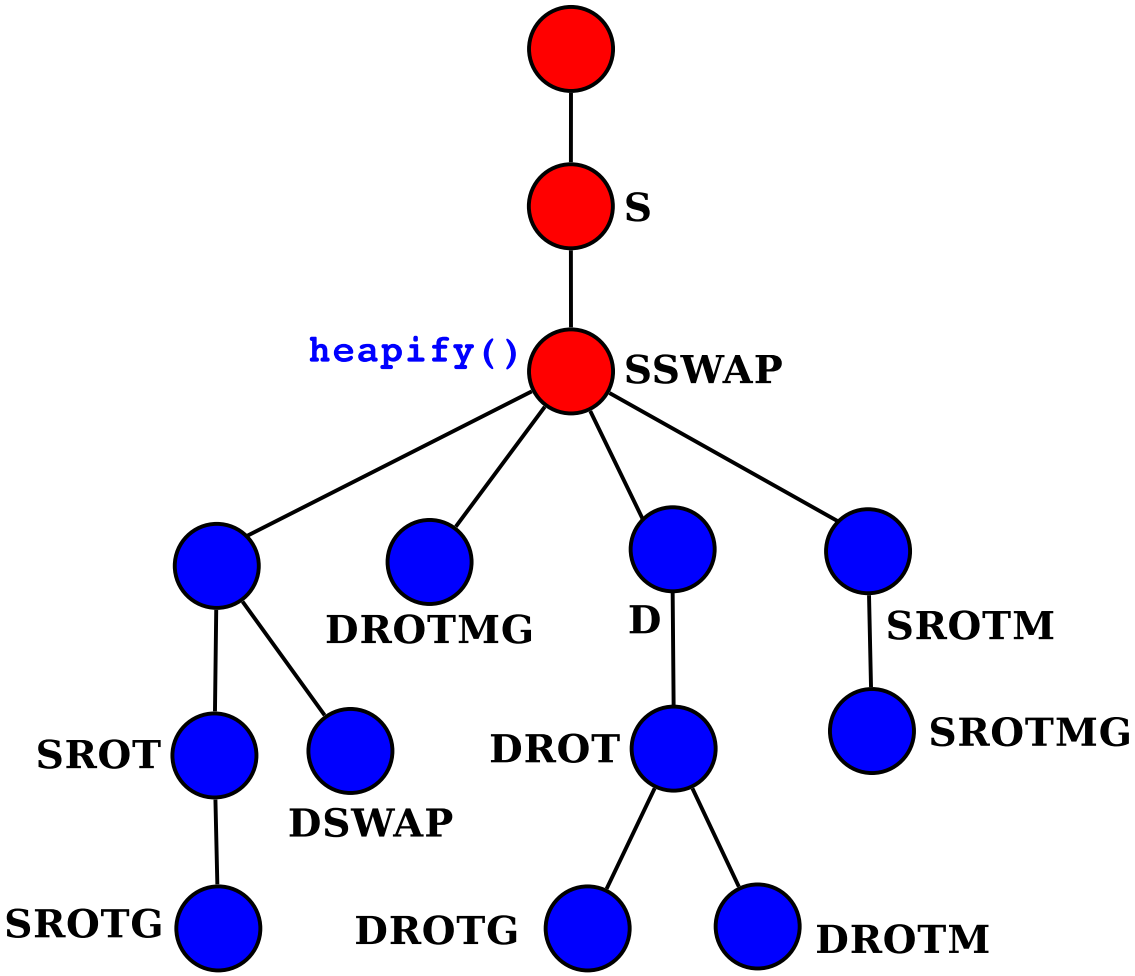
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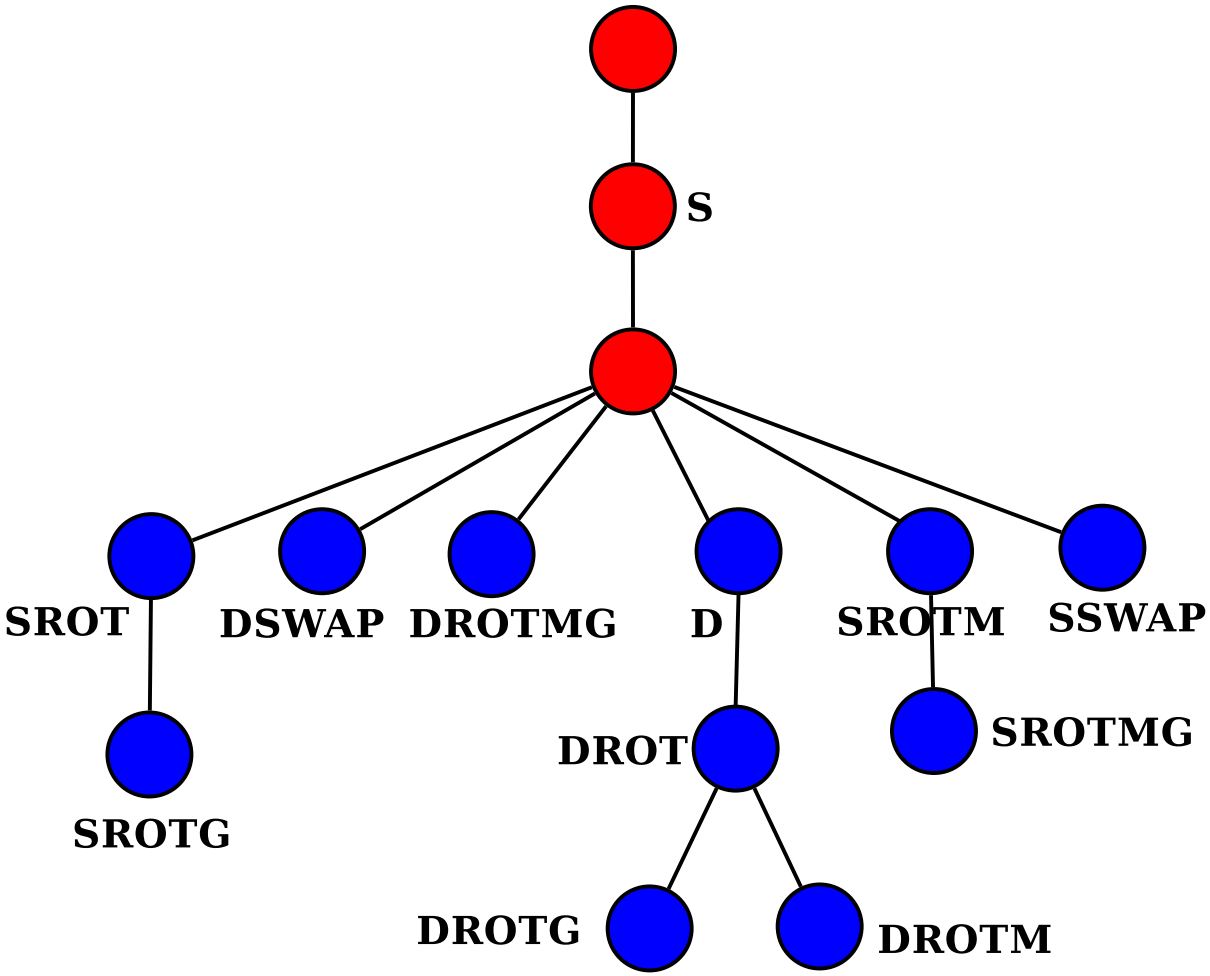
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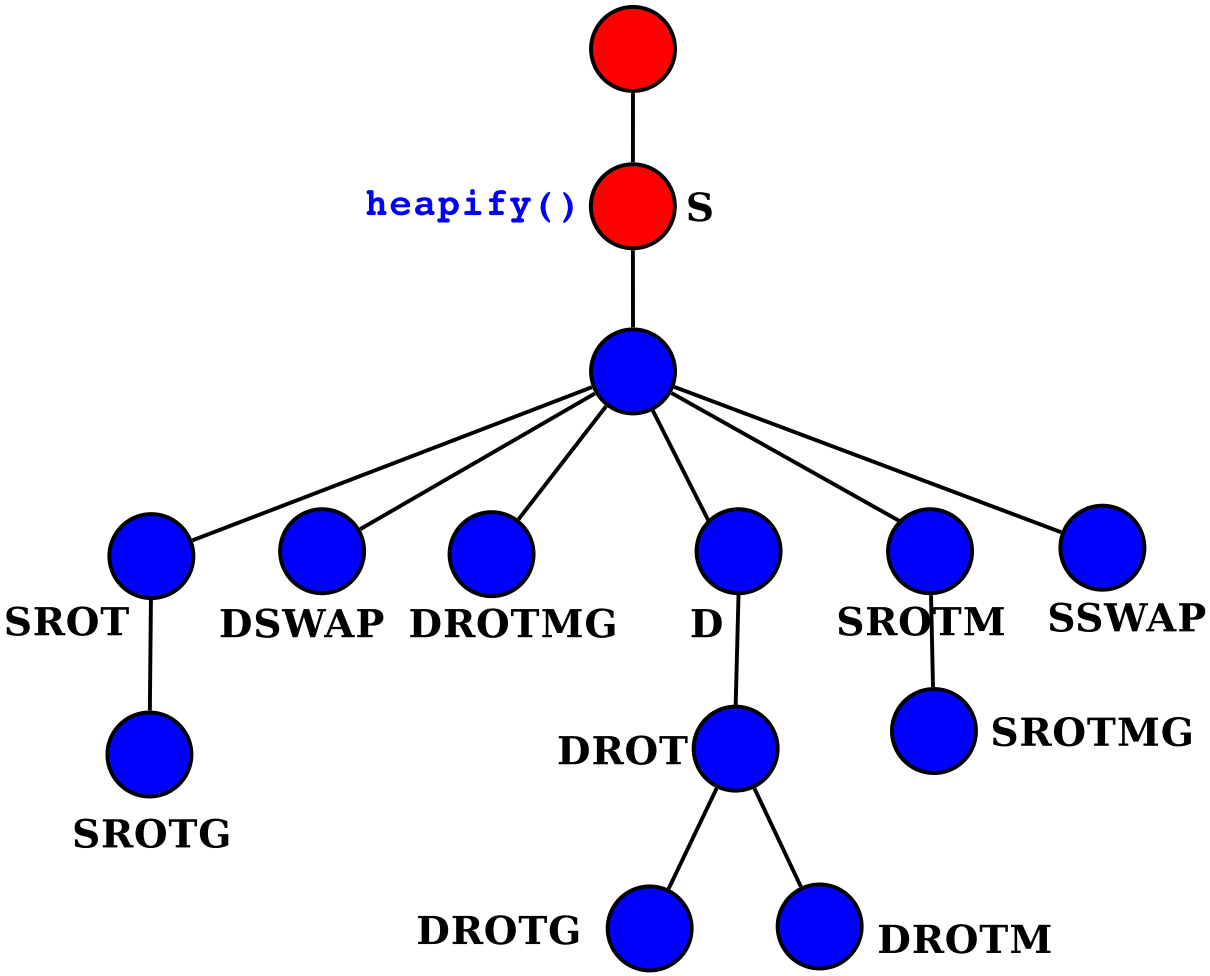
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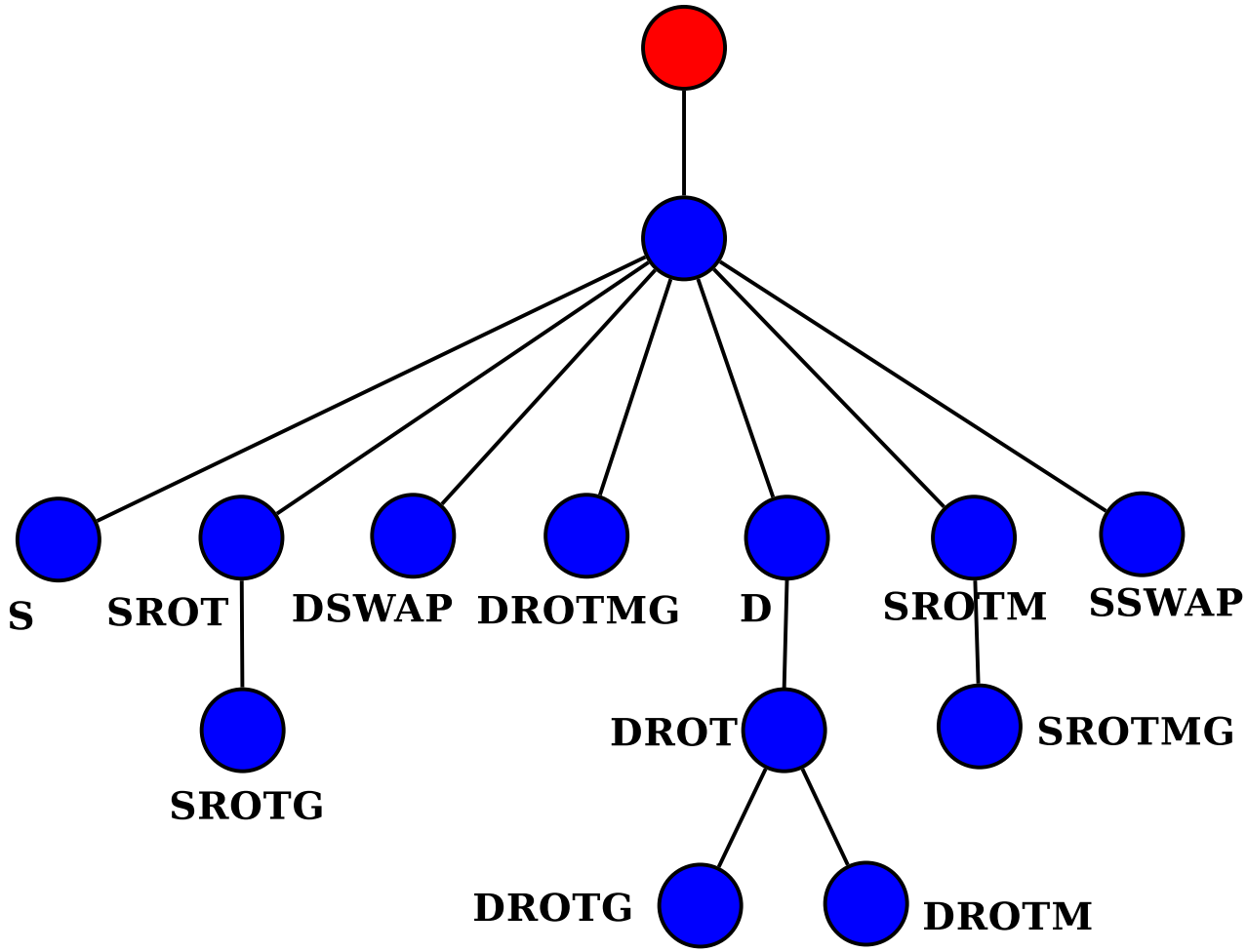
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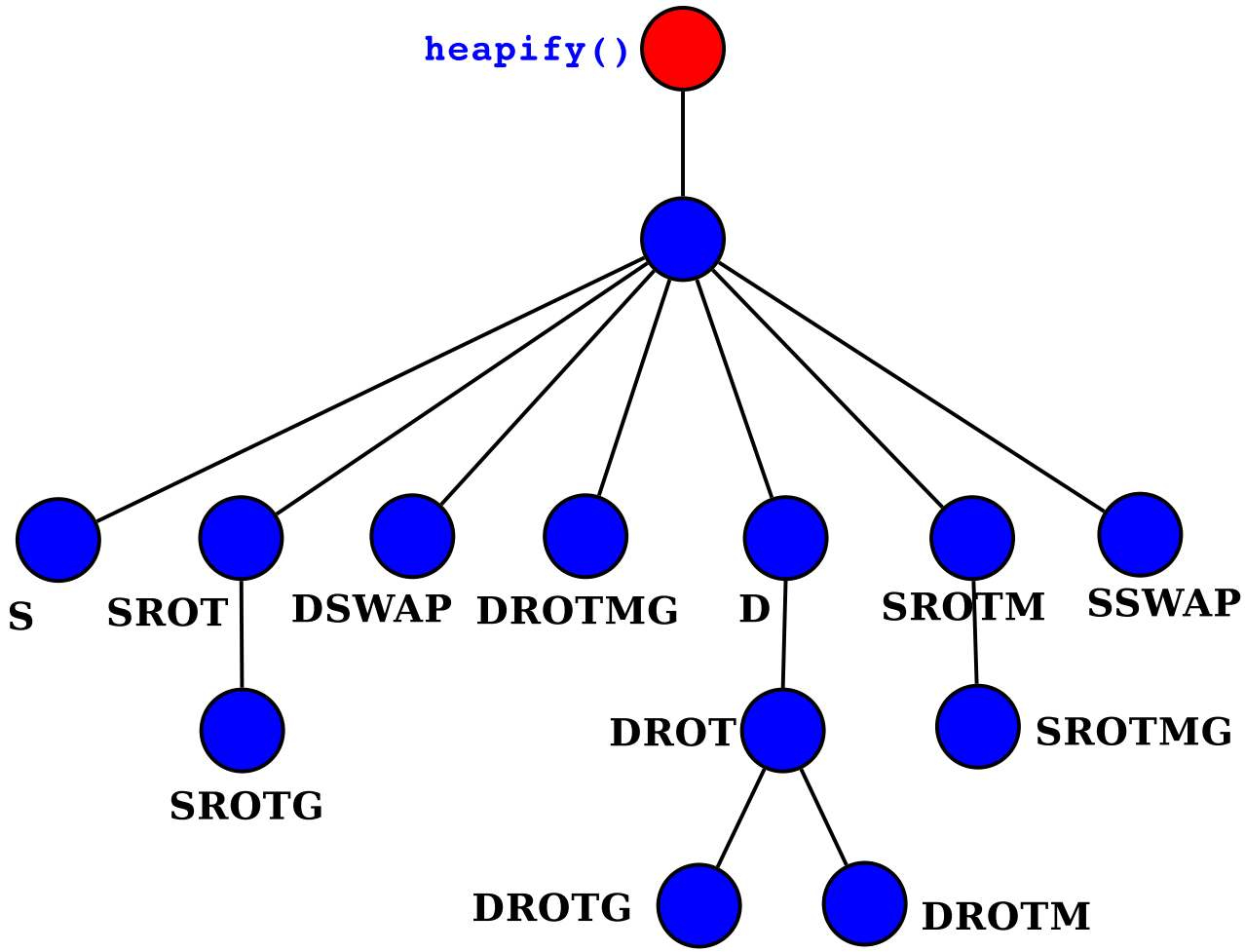
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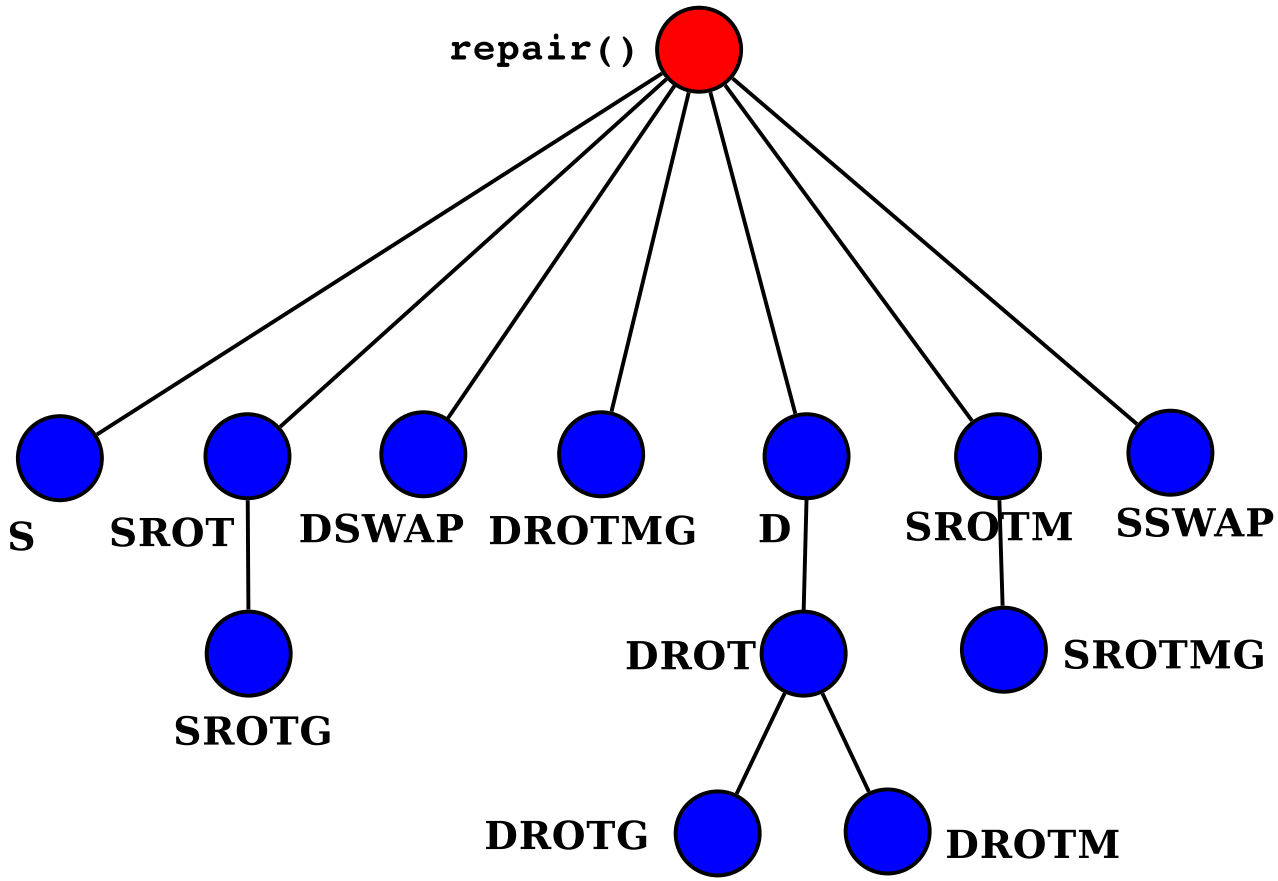
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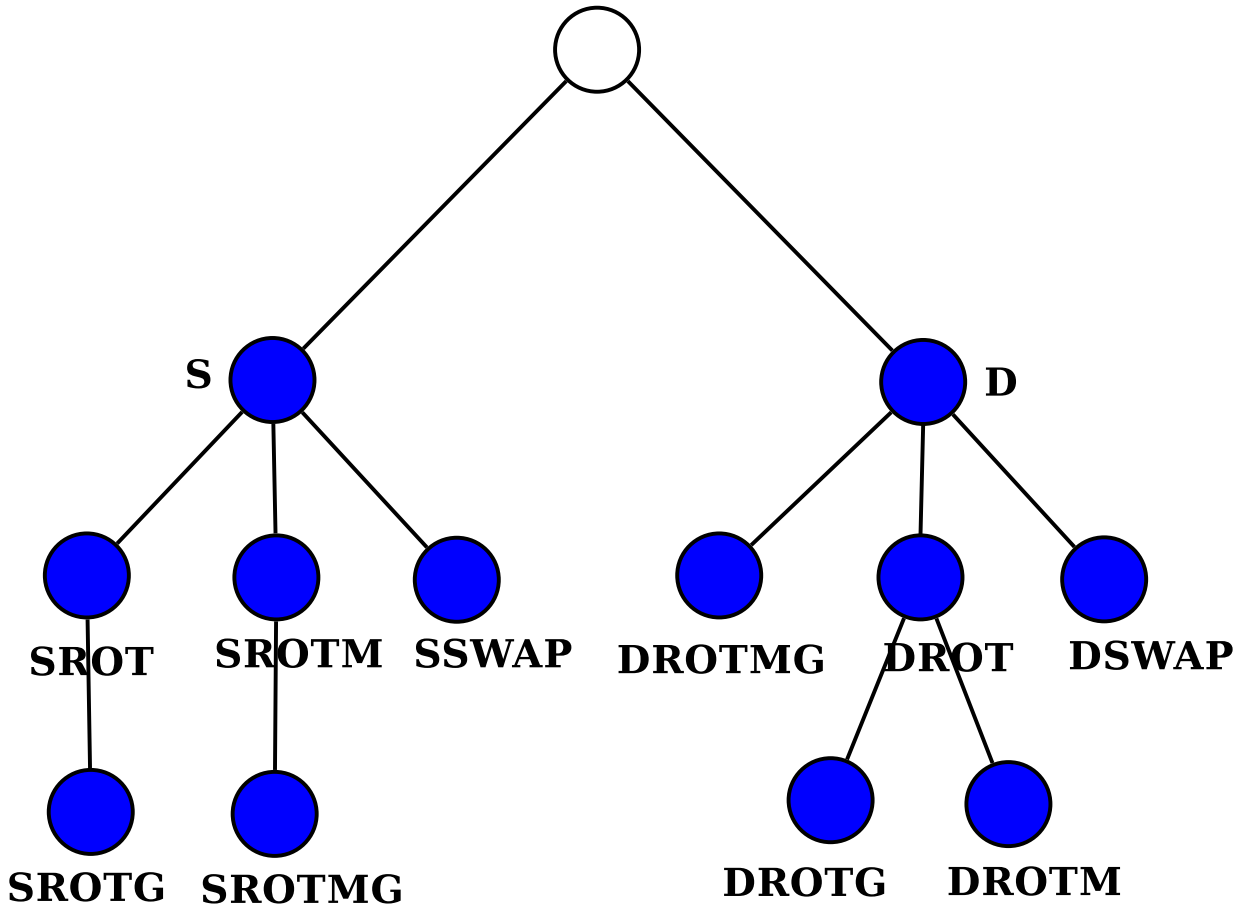
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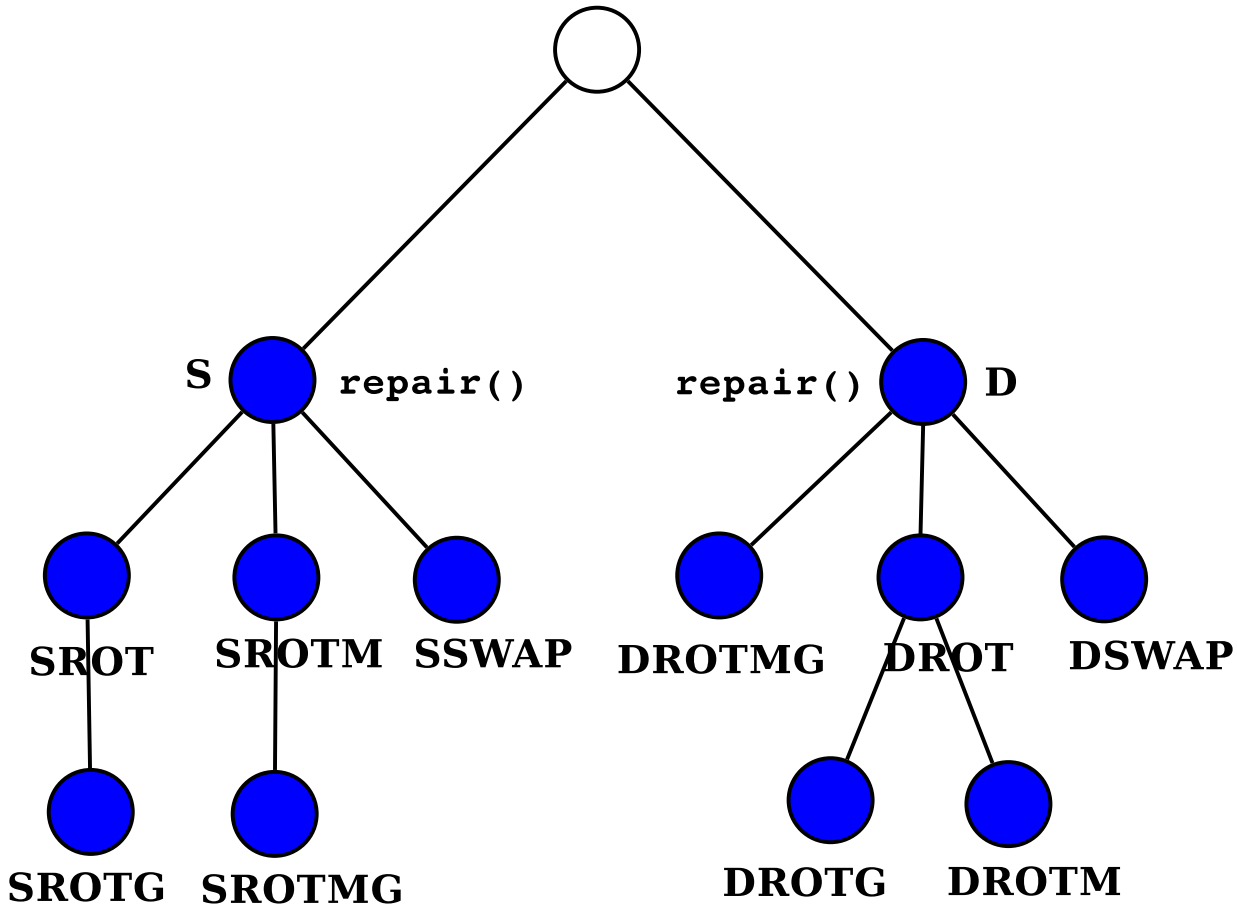
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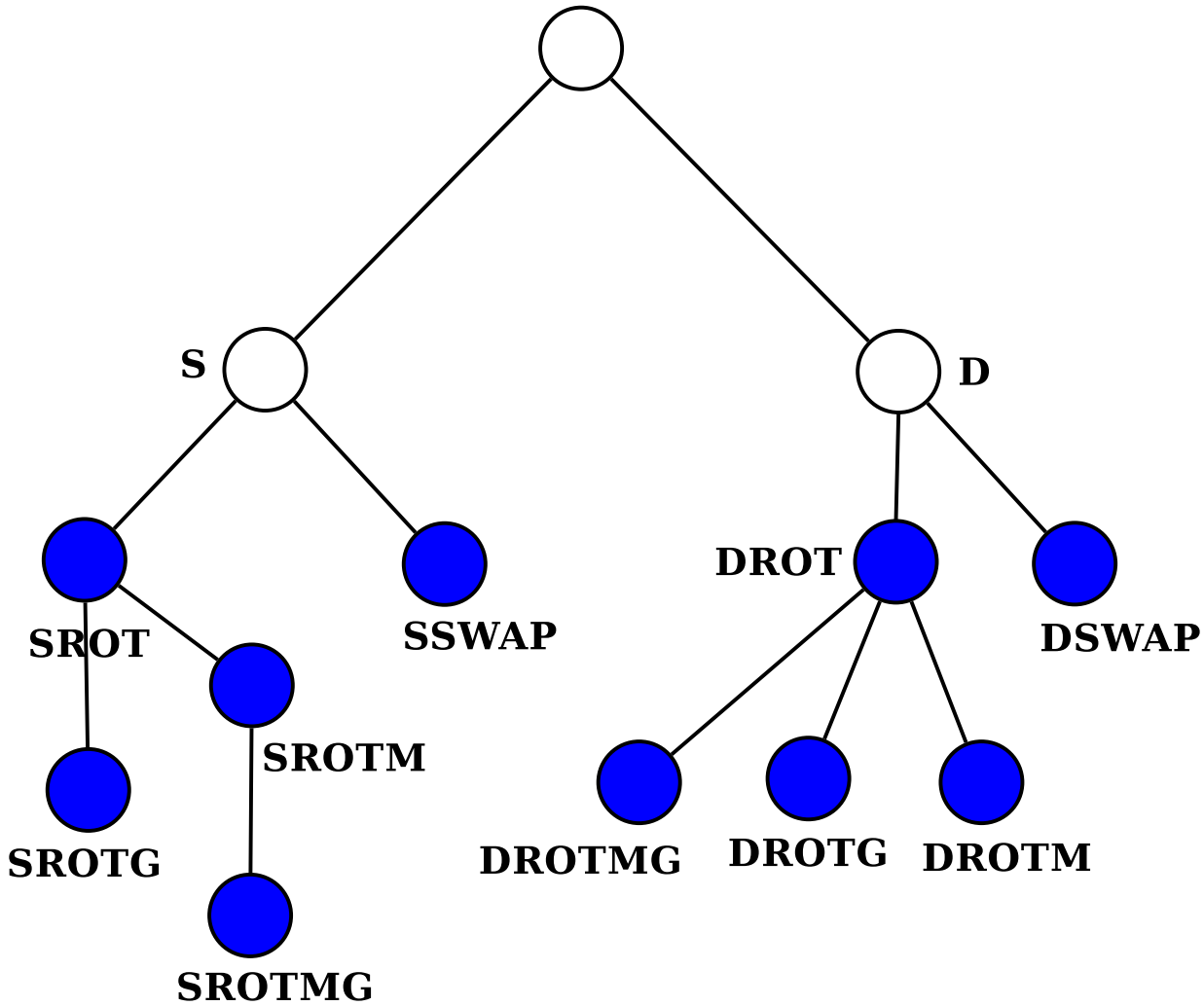
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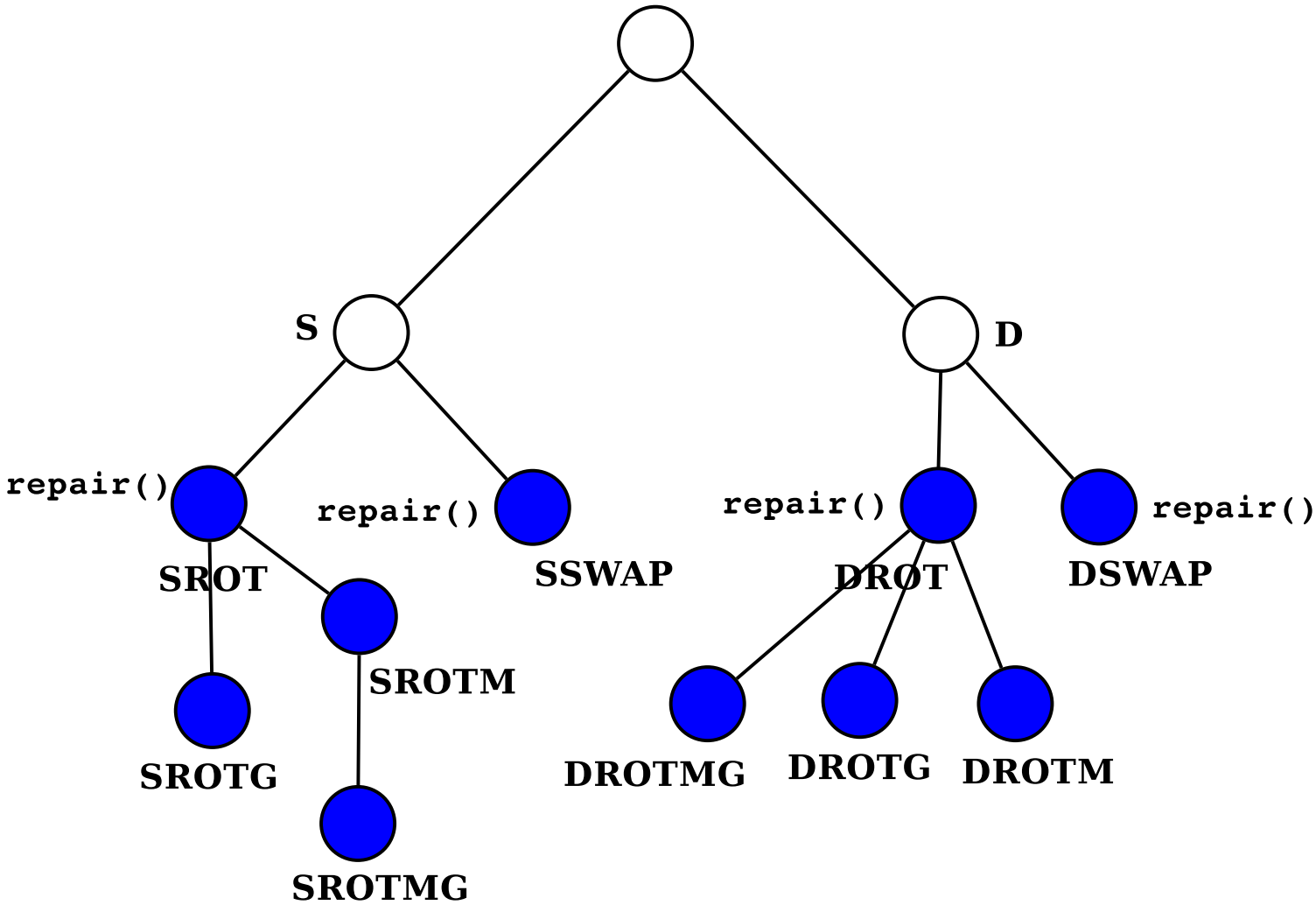
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repair()
repair()
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SROT
SSWAP
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SROTG
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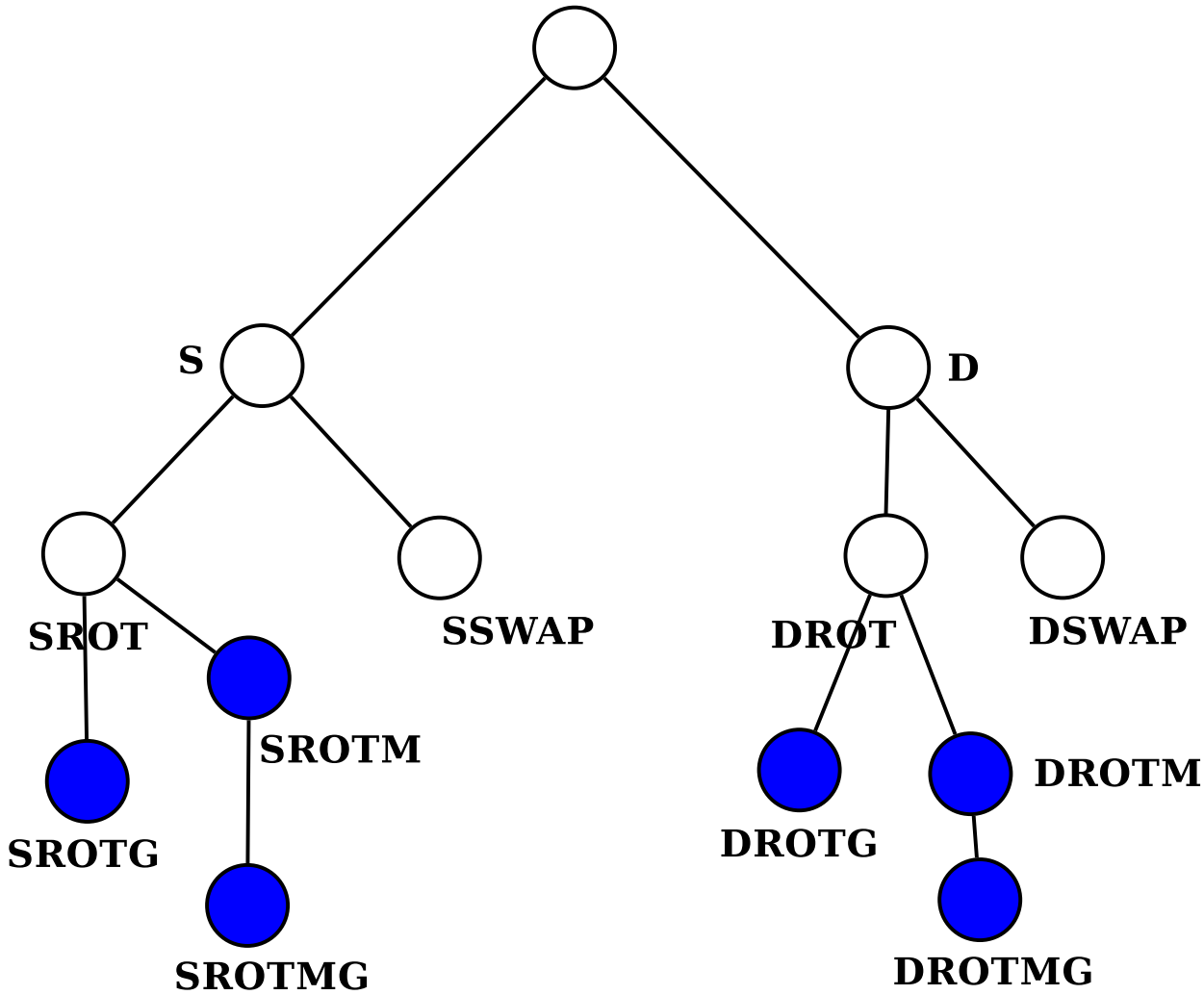
DROTG
DROTM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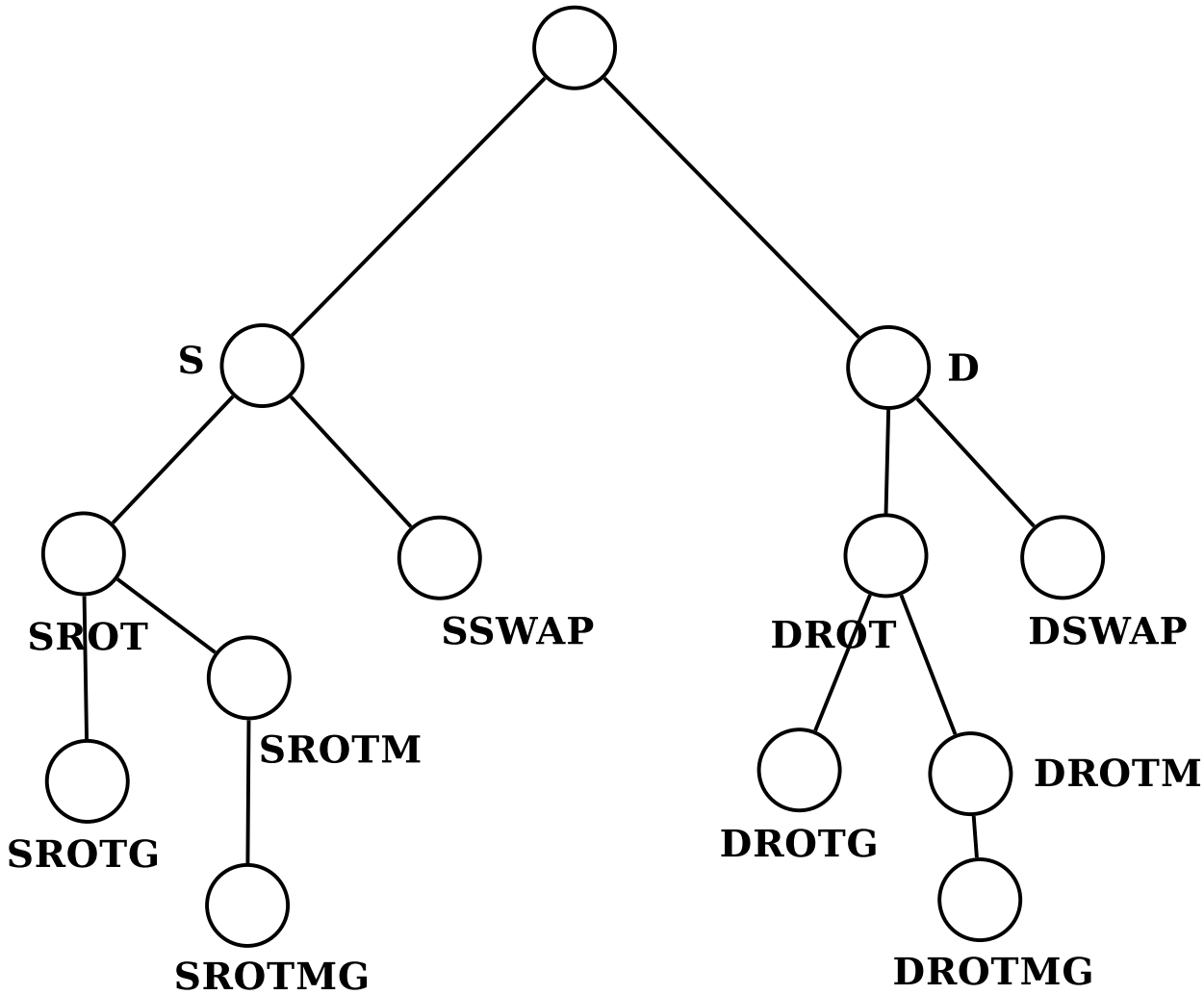
S
D
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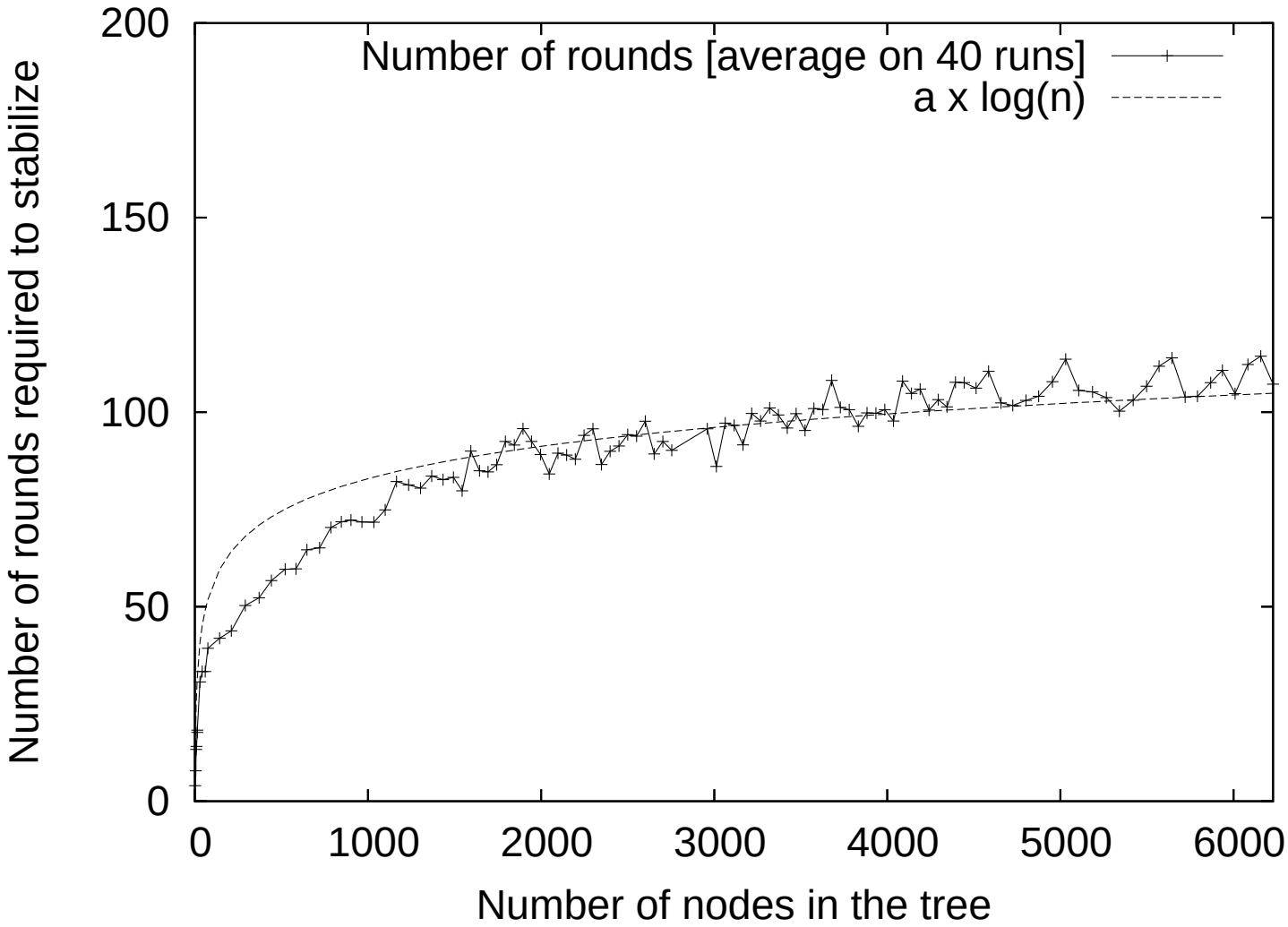
SSWAP
DROT
DSWAP
SROTM
DROTM
SROTG
DROTG
SROTMG
DROTMG

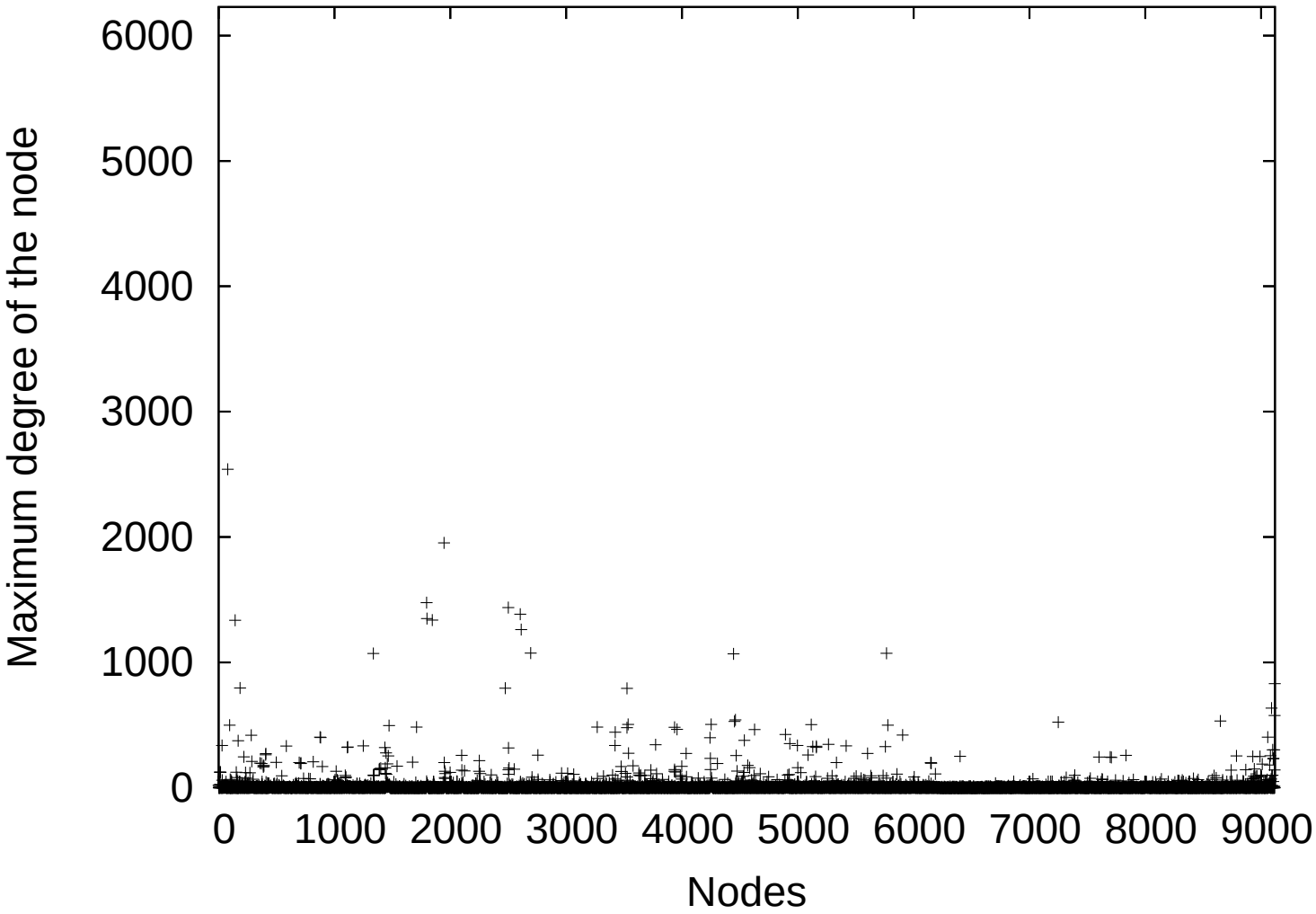
Complexities

- Average convergence time to PGCP tree : $O(h + h')$ rounds
- Worst case :
  - $O(n)$ rounds
  - $O(n^2)$ operations
  - $O(n)$ extra space (degree)

Simulation : Time Complexity



Simulation : Extra Space



Snap in State Model *vs* Self in Message Passing

Snap : Drawbacks

- Assumes a rooted connected tree
- Written in a coarse grain communication model

A New Protocol

- Work with any initial topology
- Designed in the message passing model

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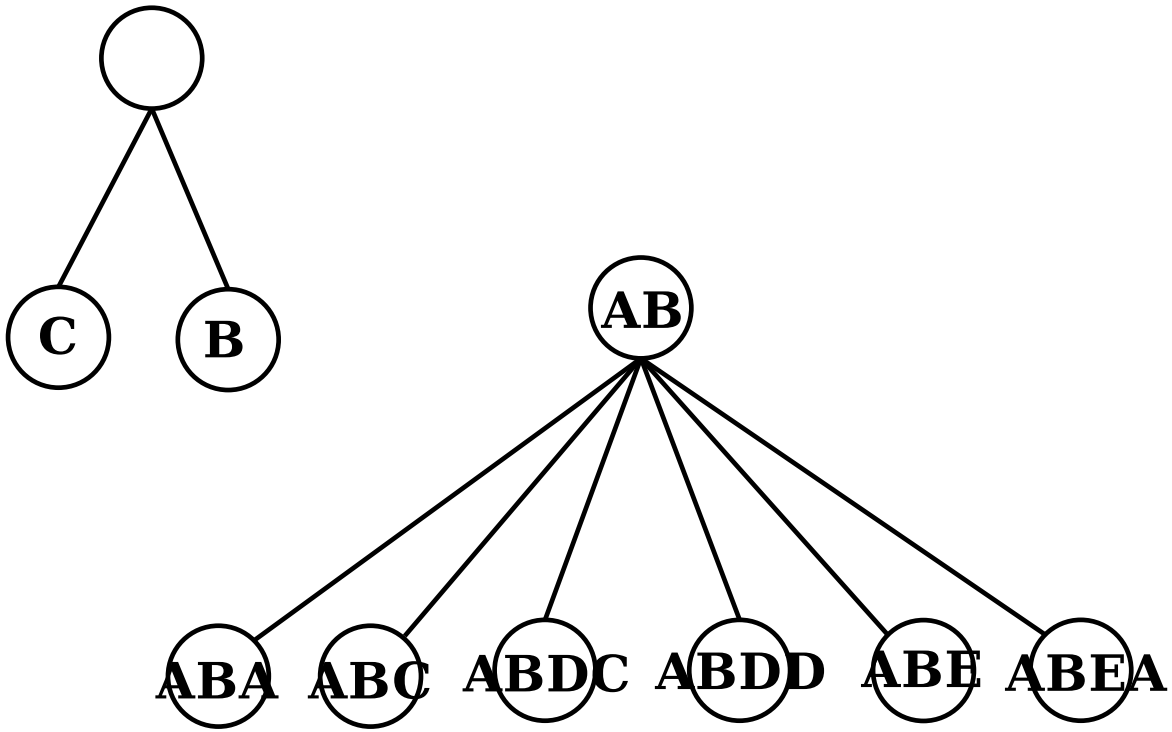
Steps

- Launched periodically on each node
- 1 - Parent processing
- 2 - Children processing


C
B
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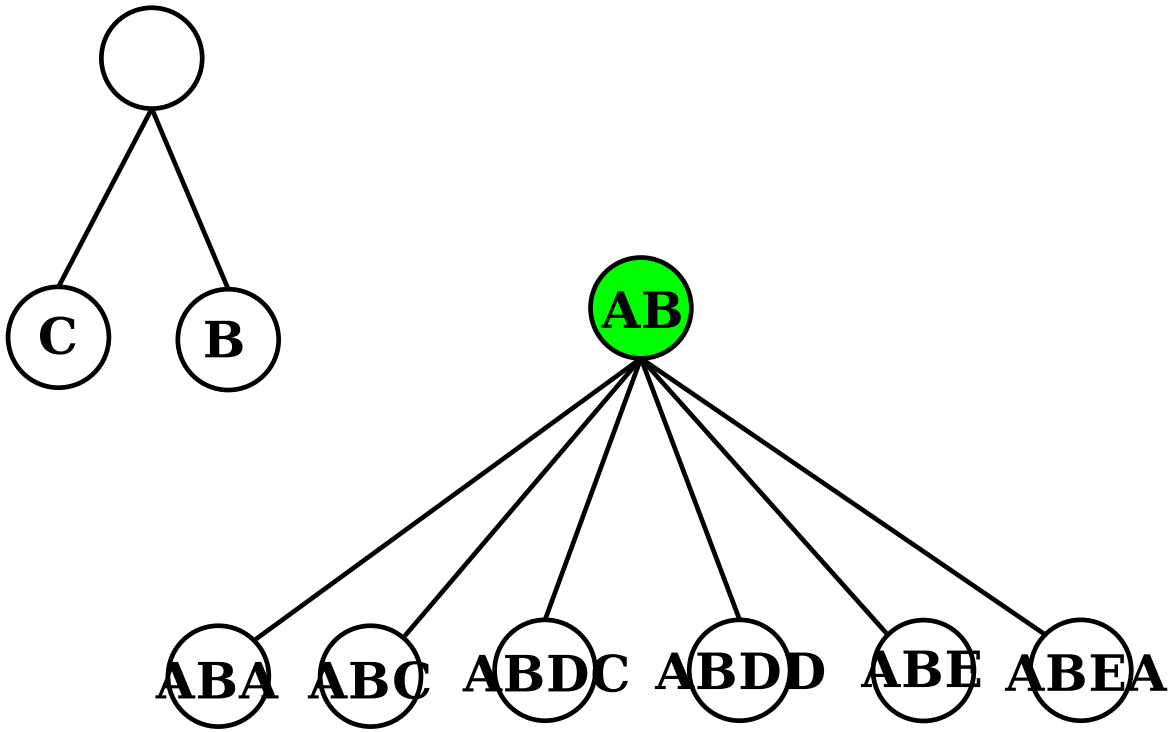
C
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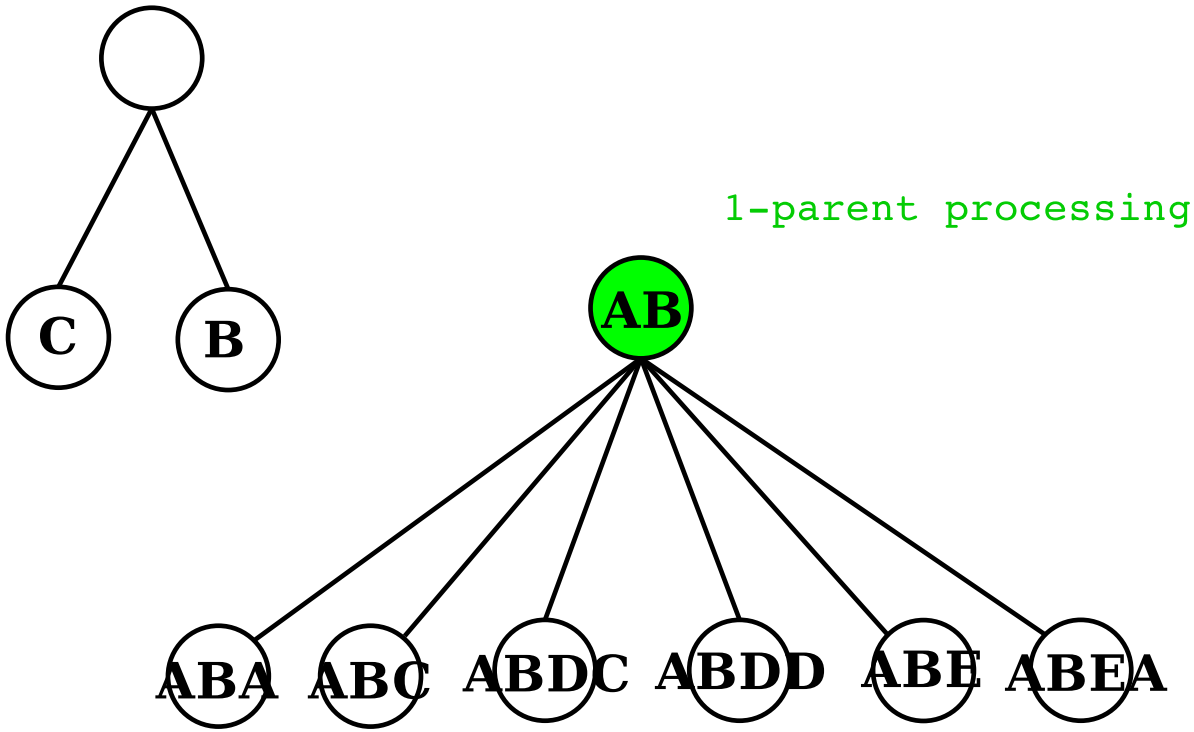
C
B
1-parent processing
AB
ABA
ABC
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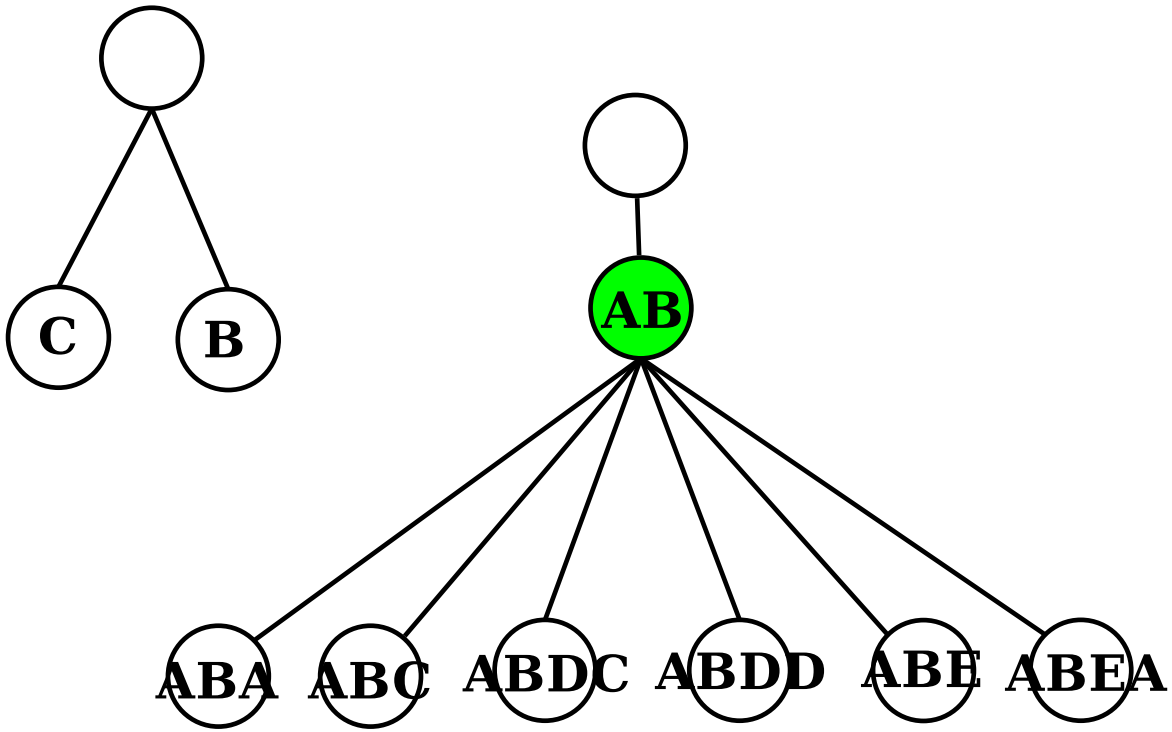
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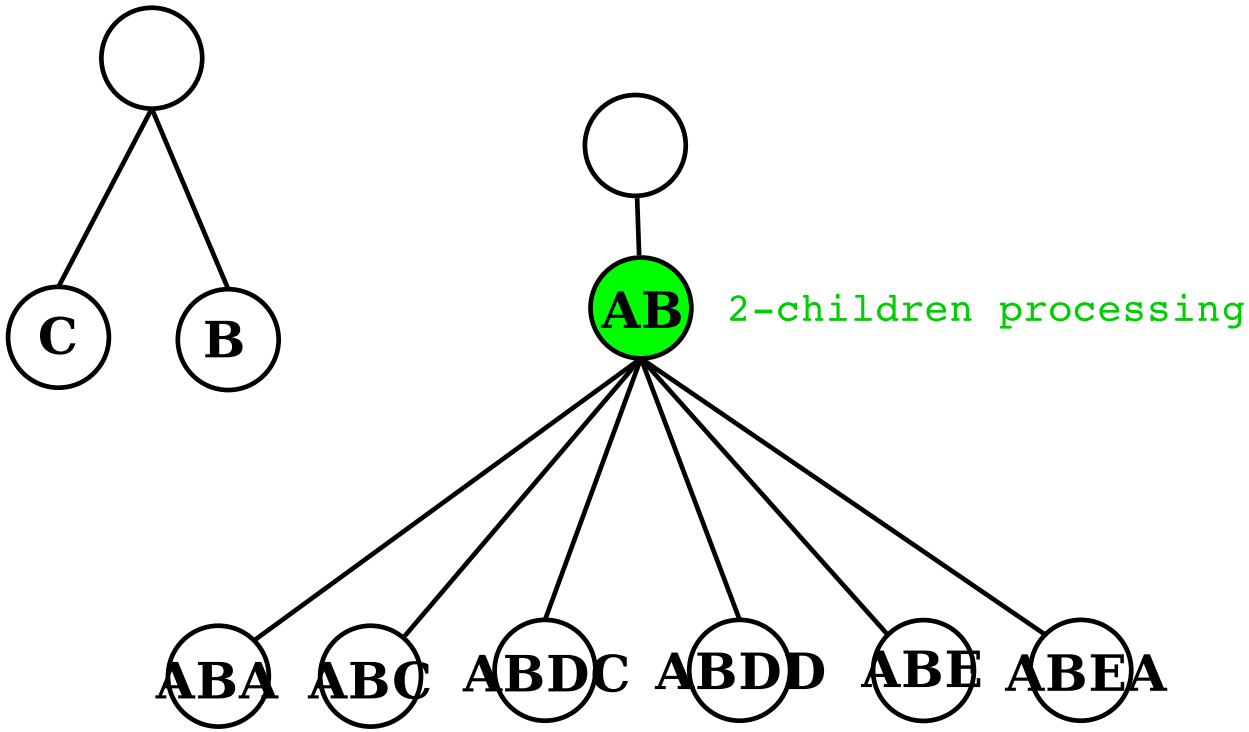
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ABC
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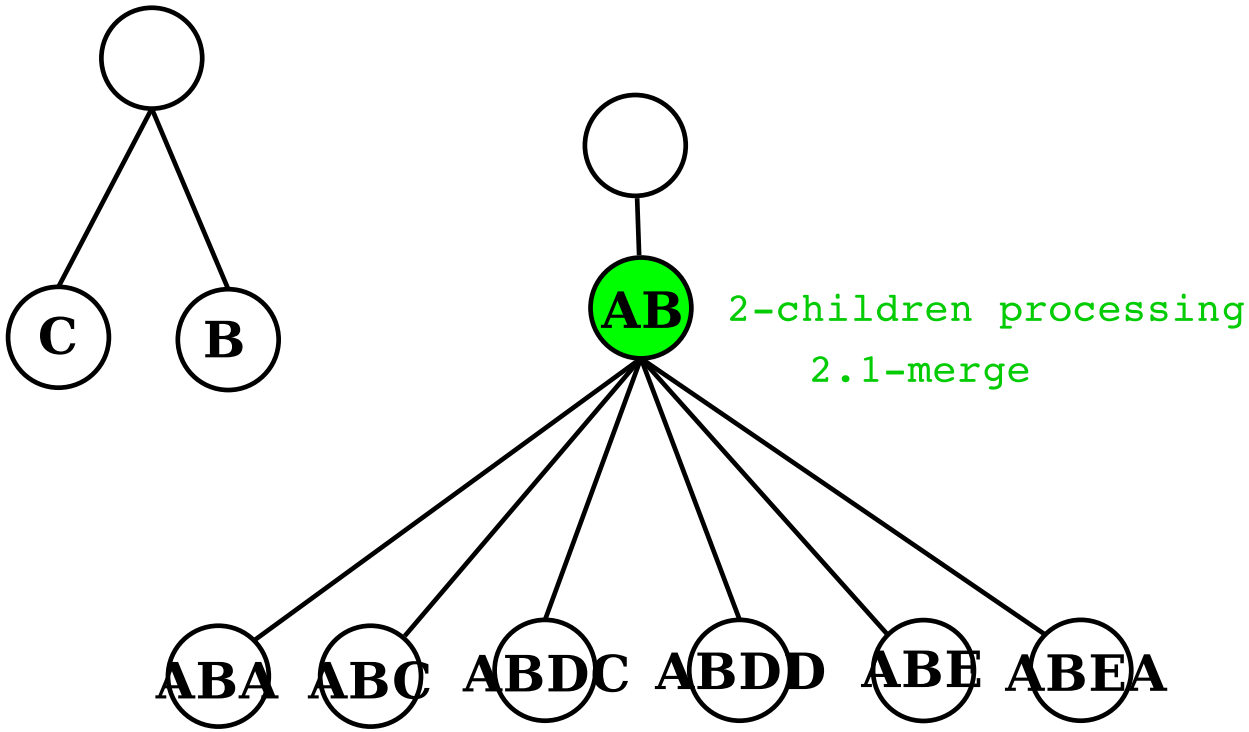
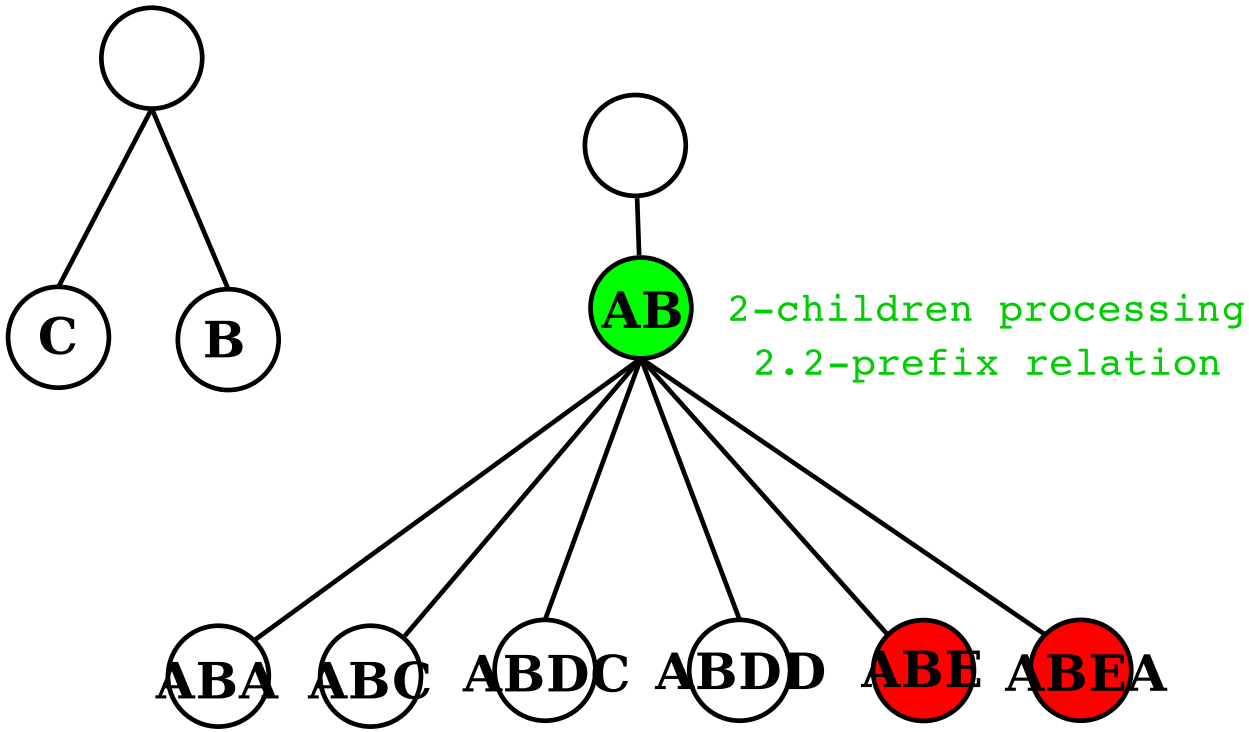
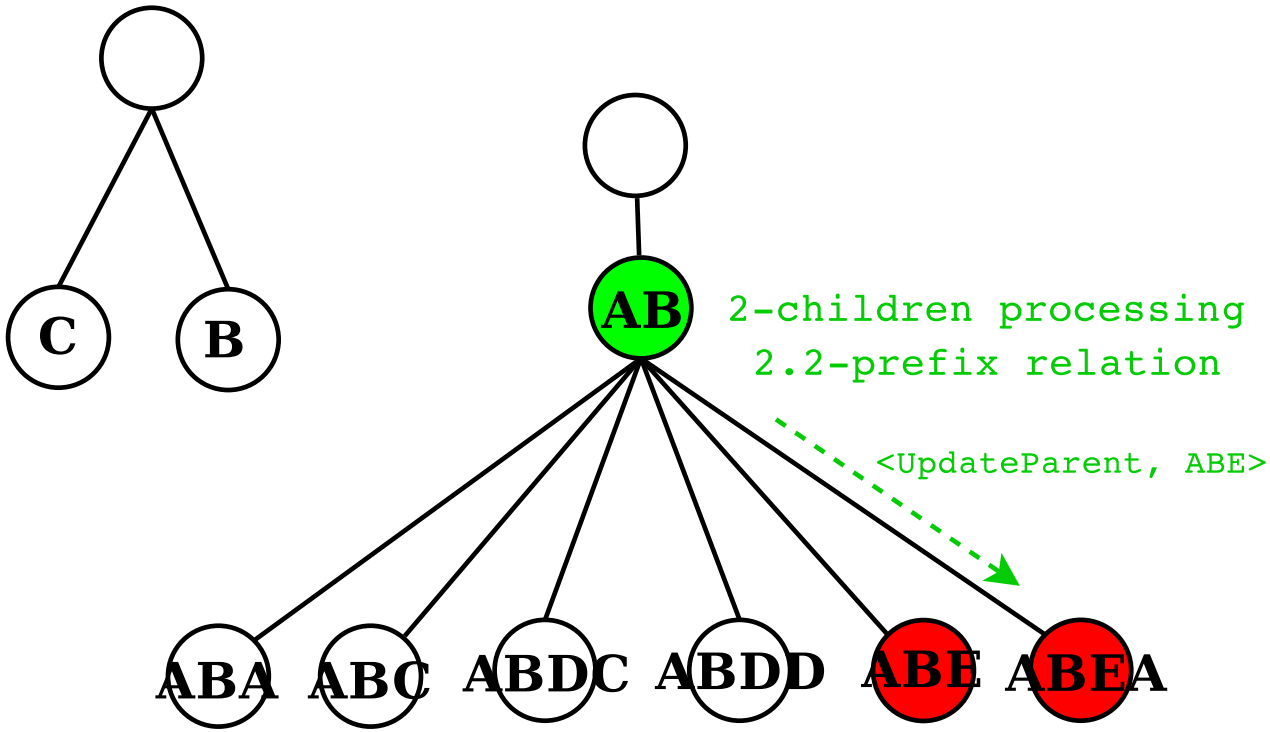

C
B
AB
2-children processing
2.1-merge
ABA
ABC
ABDC
ABDD
ABE
ABEA


C
B
AB
2-children processing
2.2-prefix relation
ABA
ABC
ABDC
ABDD
ABE
ABEA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B
AB
2-children processing
2.2-prefix relation
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ABA
ABC
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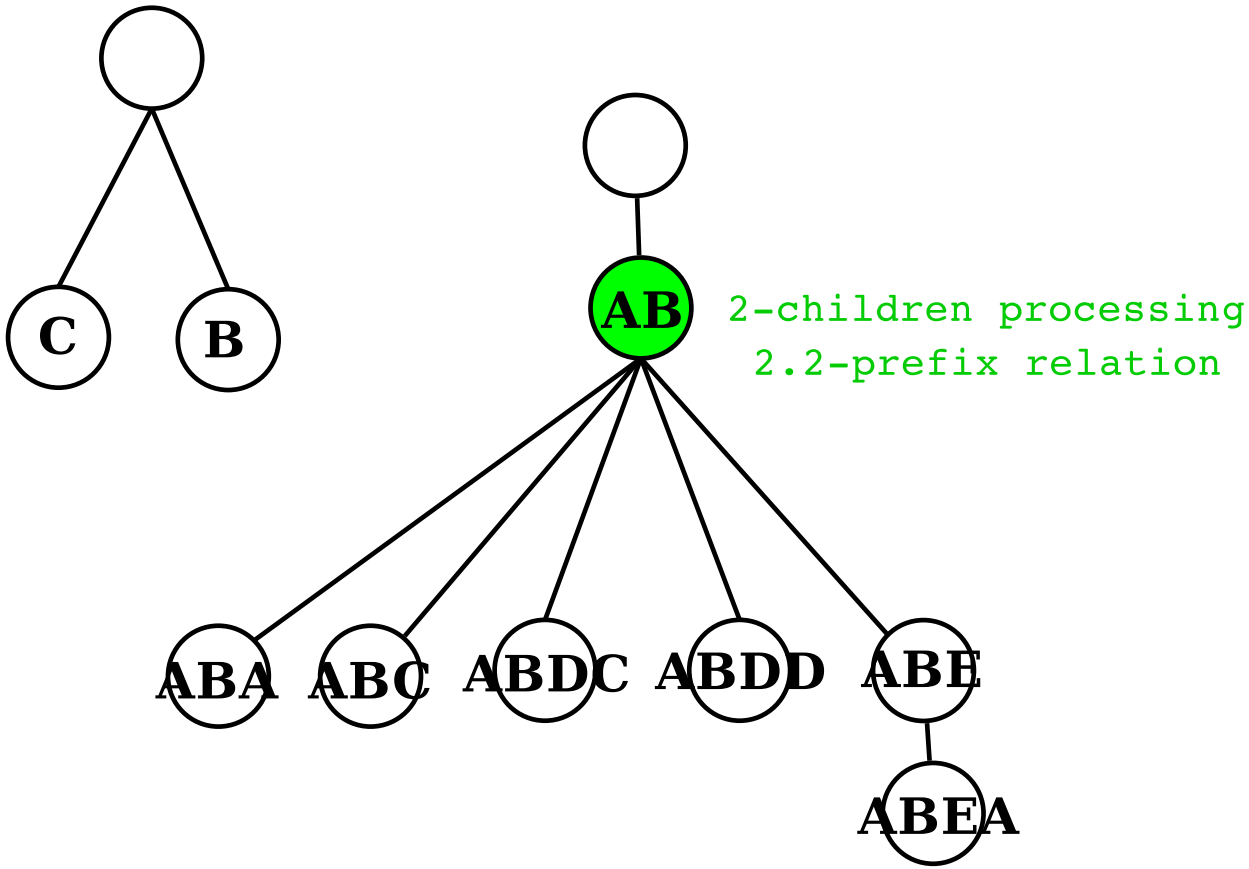
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2.2-prefix relation
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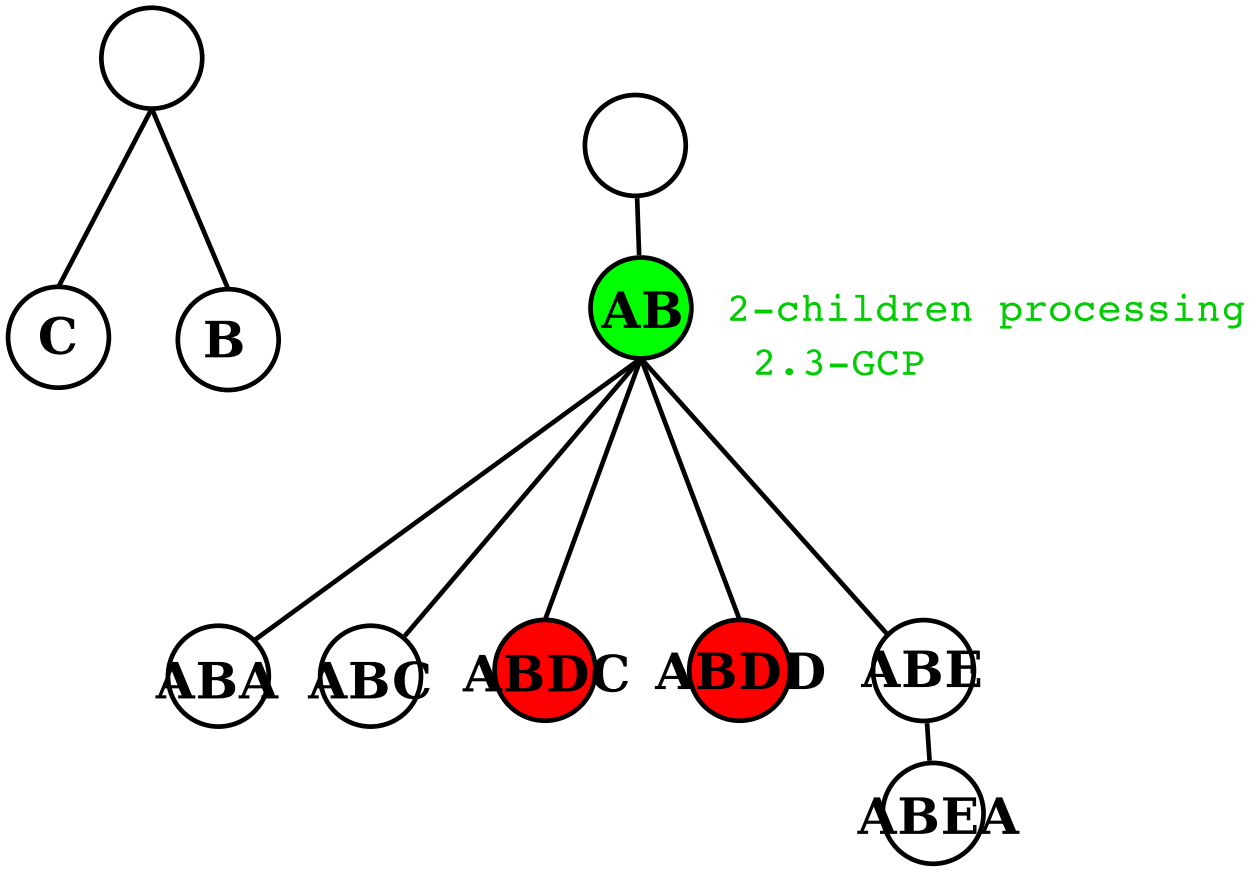
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2.3-GCP
ABA
ABC
ABDC
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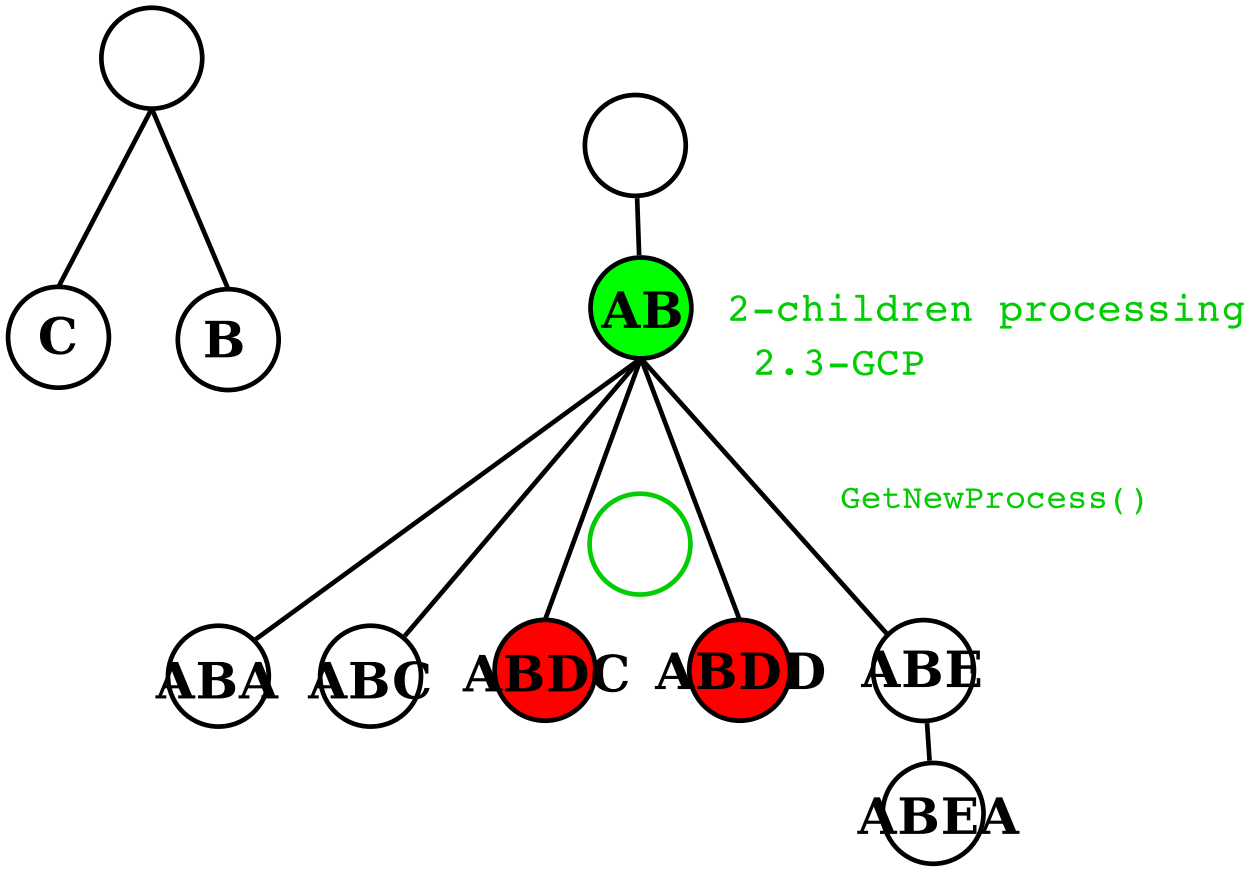
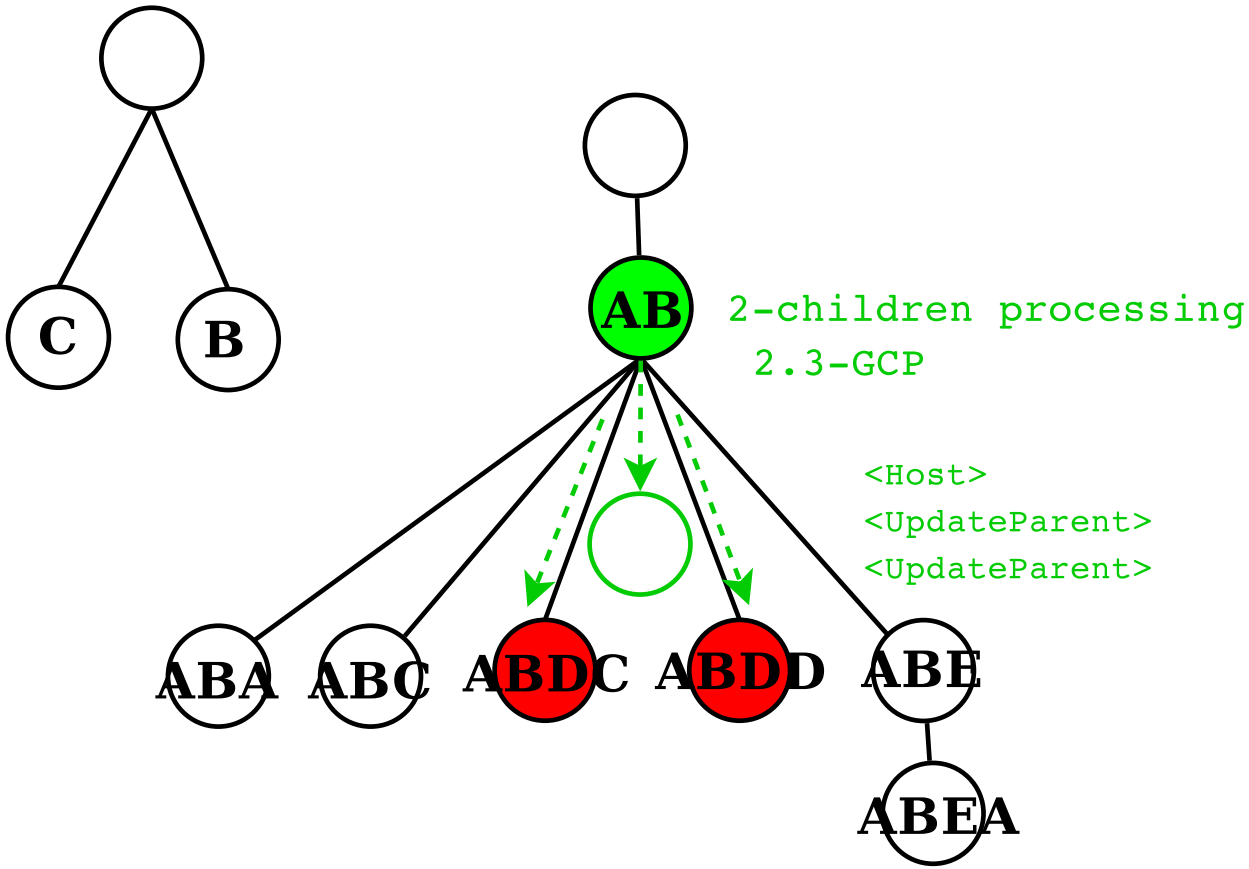
ABE
ABEA


C
B
AB
2-children processing
2.3-GCP
GetNewProcess()
ABA
ABC
ABDC
ABDD
ABE
ABEA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AB
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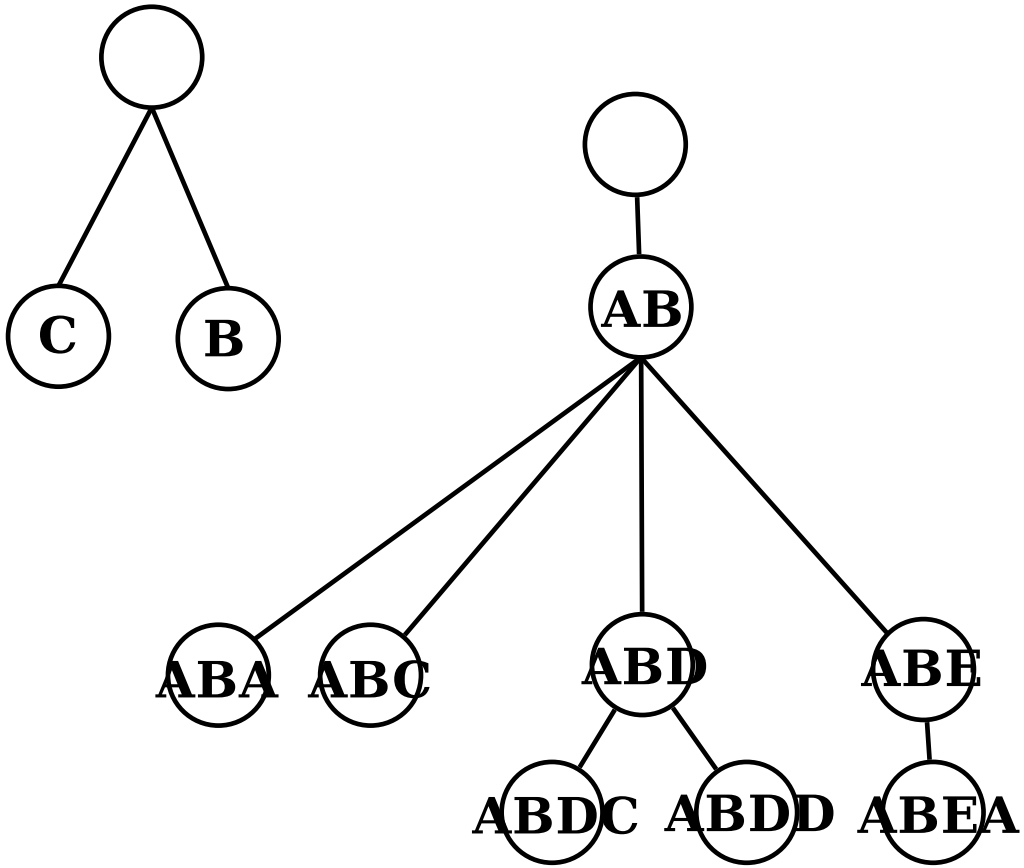
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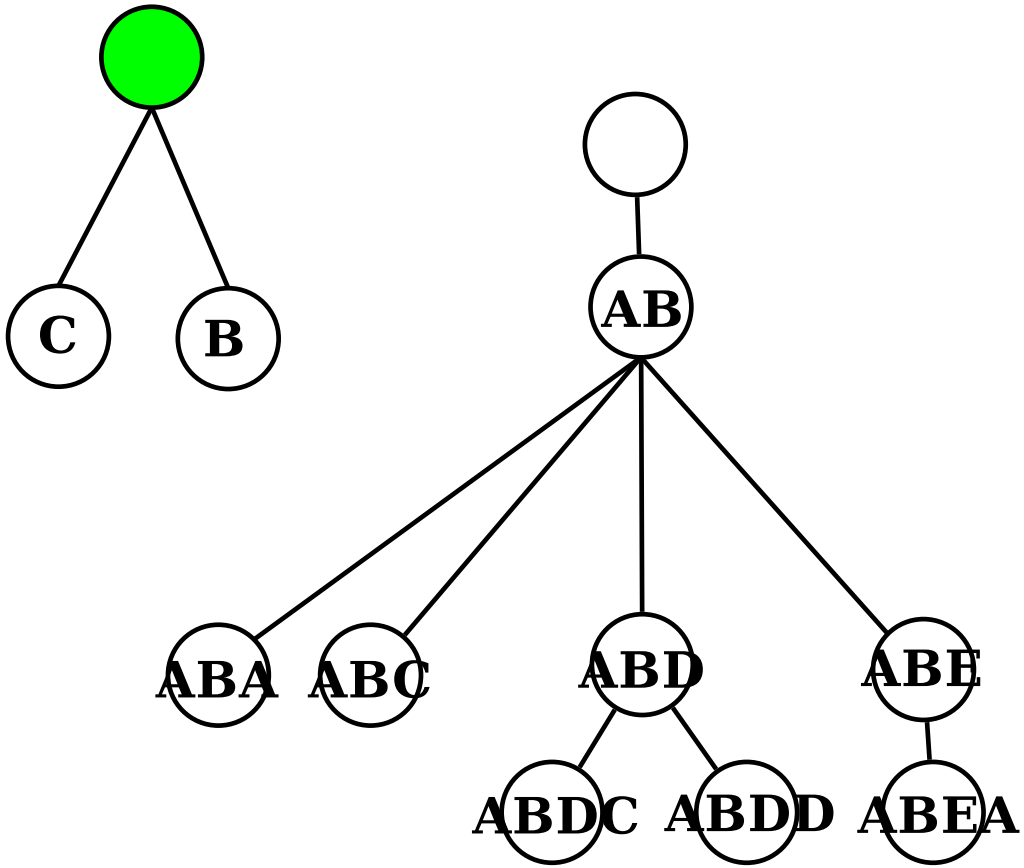
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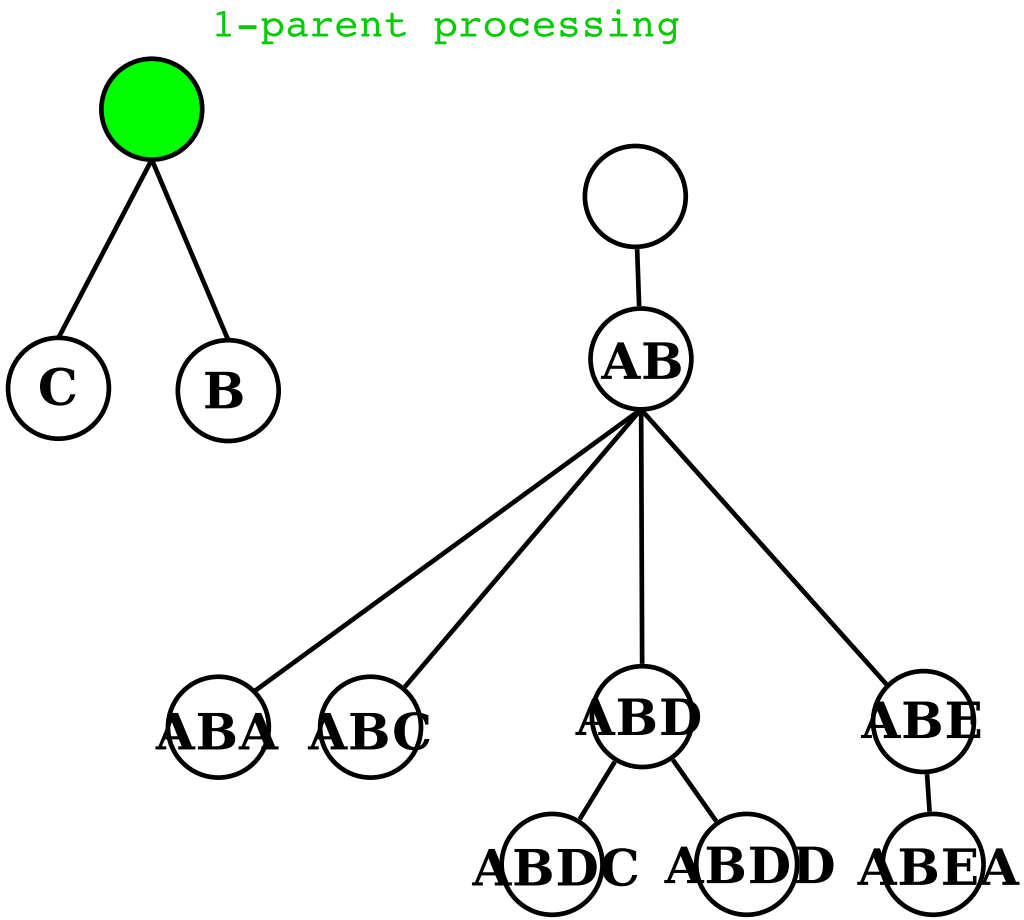
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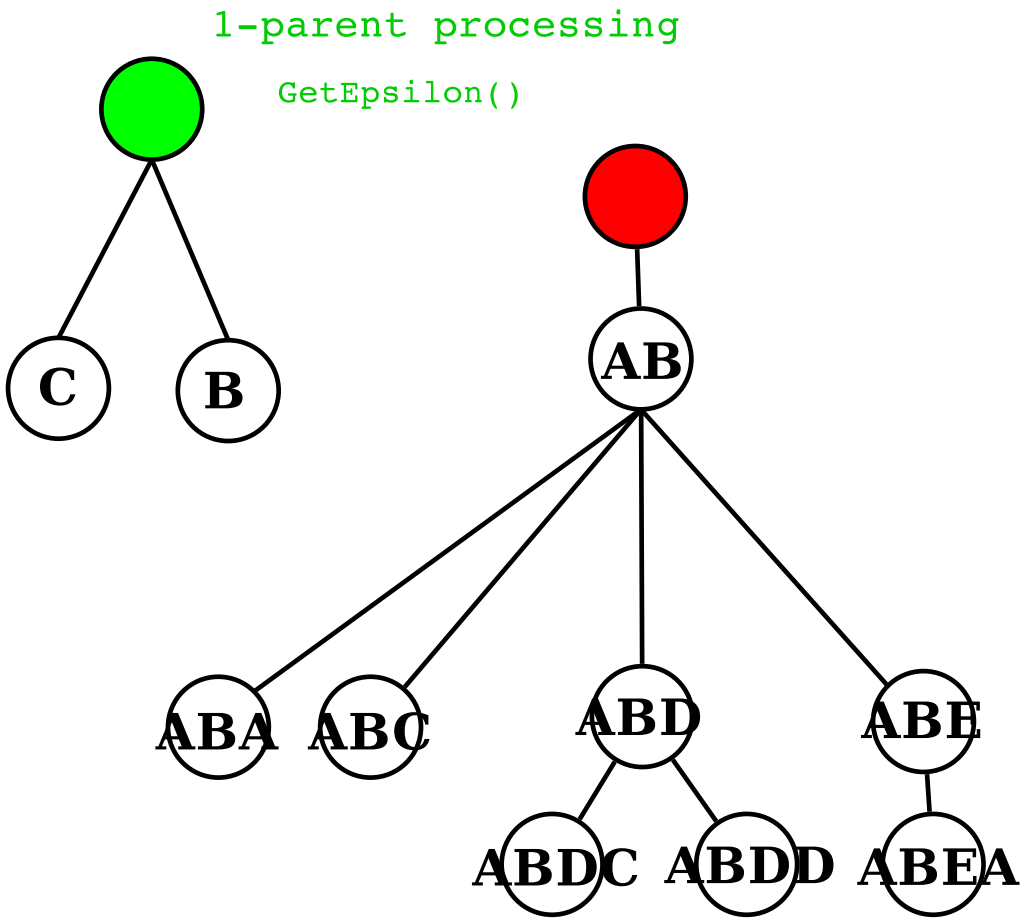
1-parent processing
GetEpsilon()
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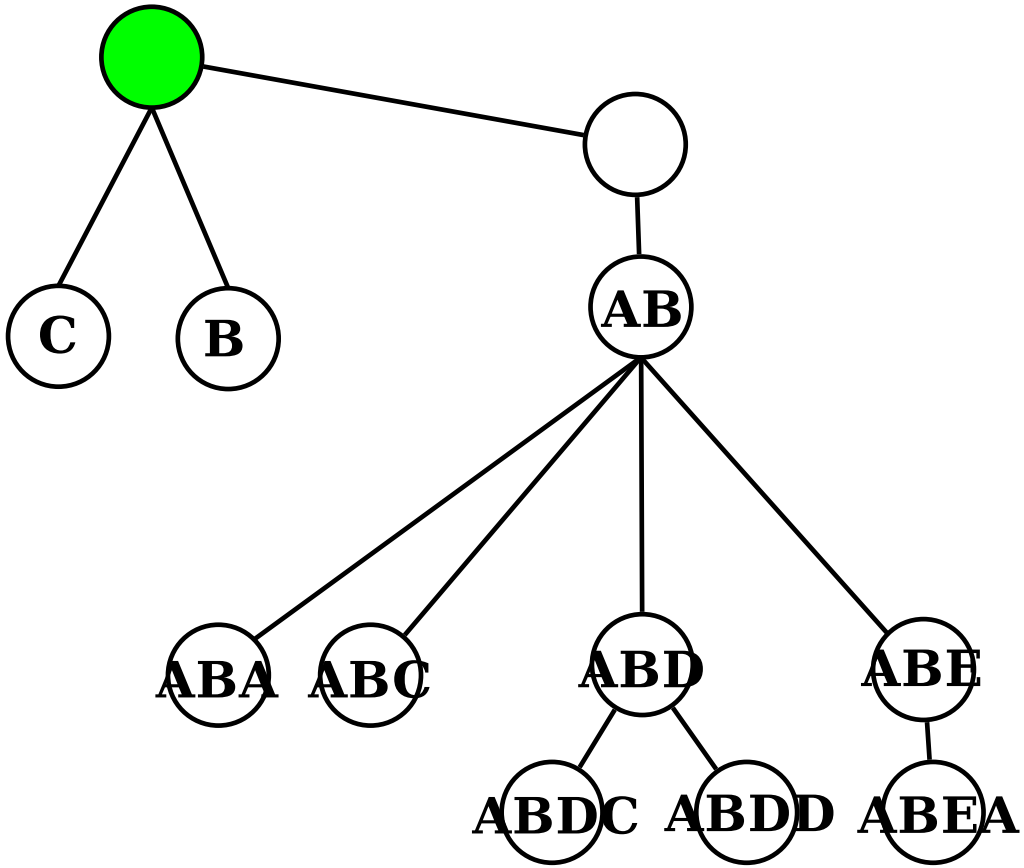
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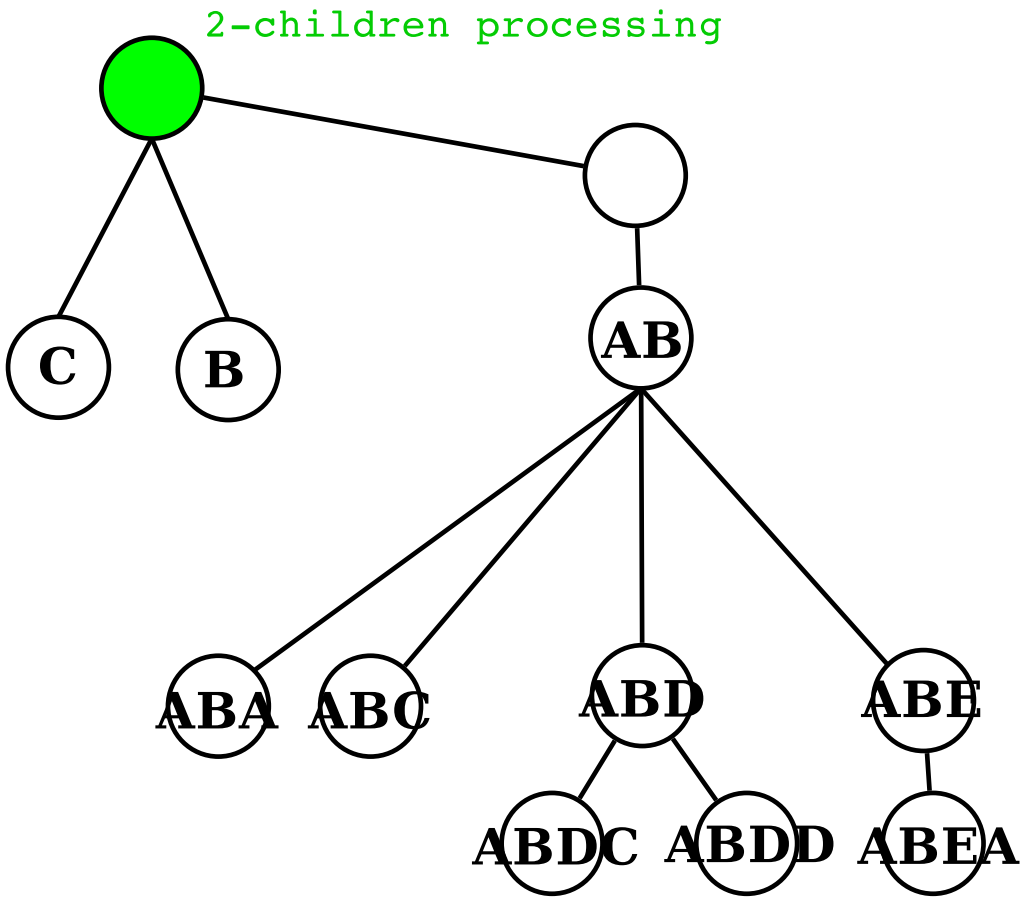
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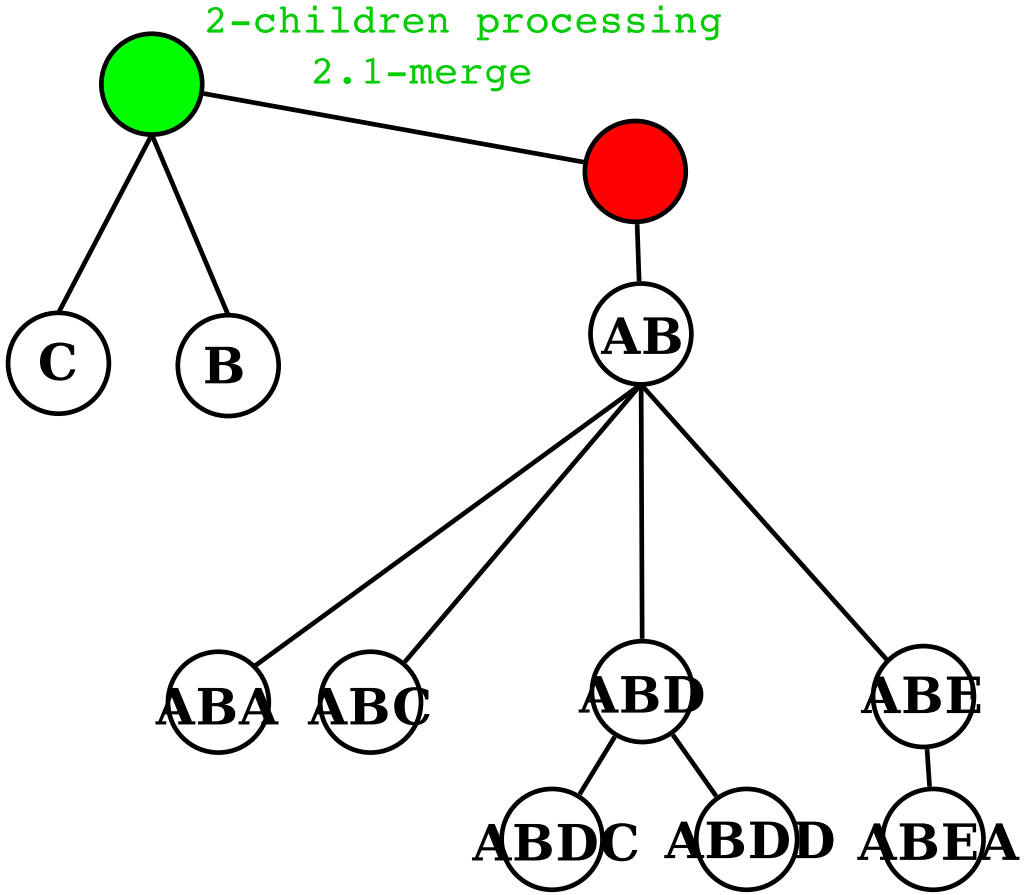
2-children processing
2.1-merge
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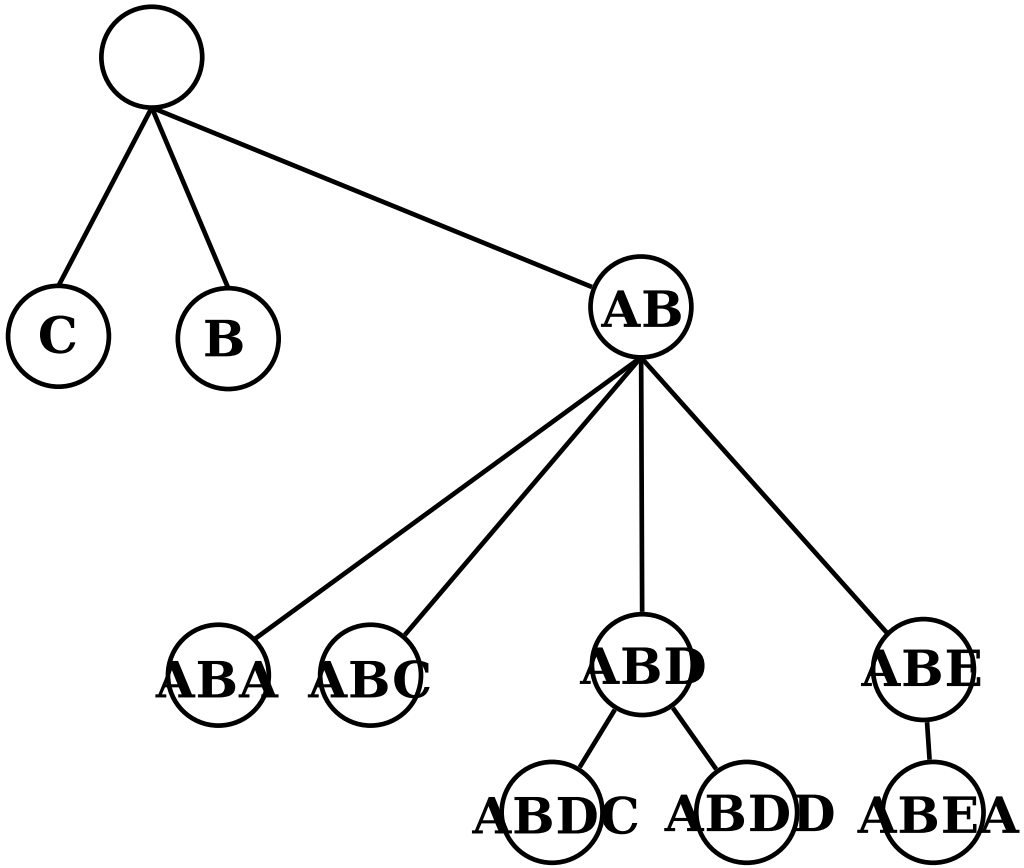
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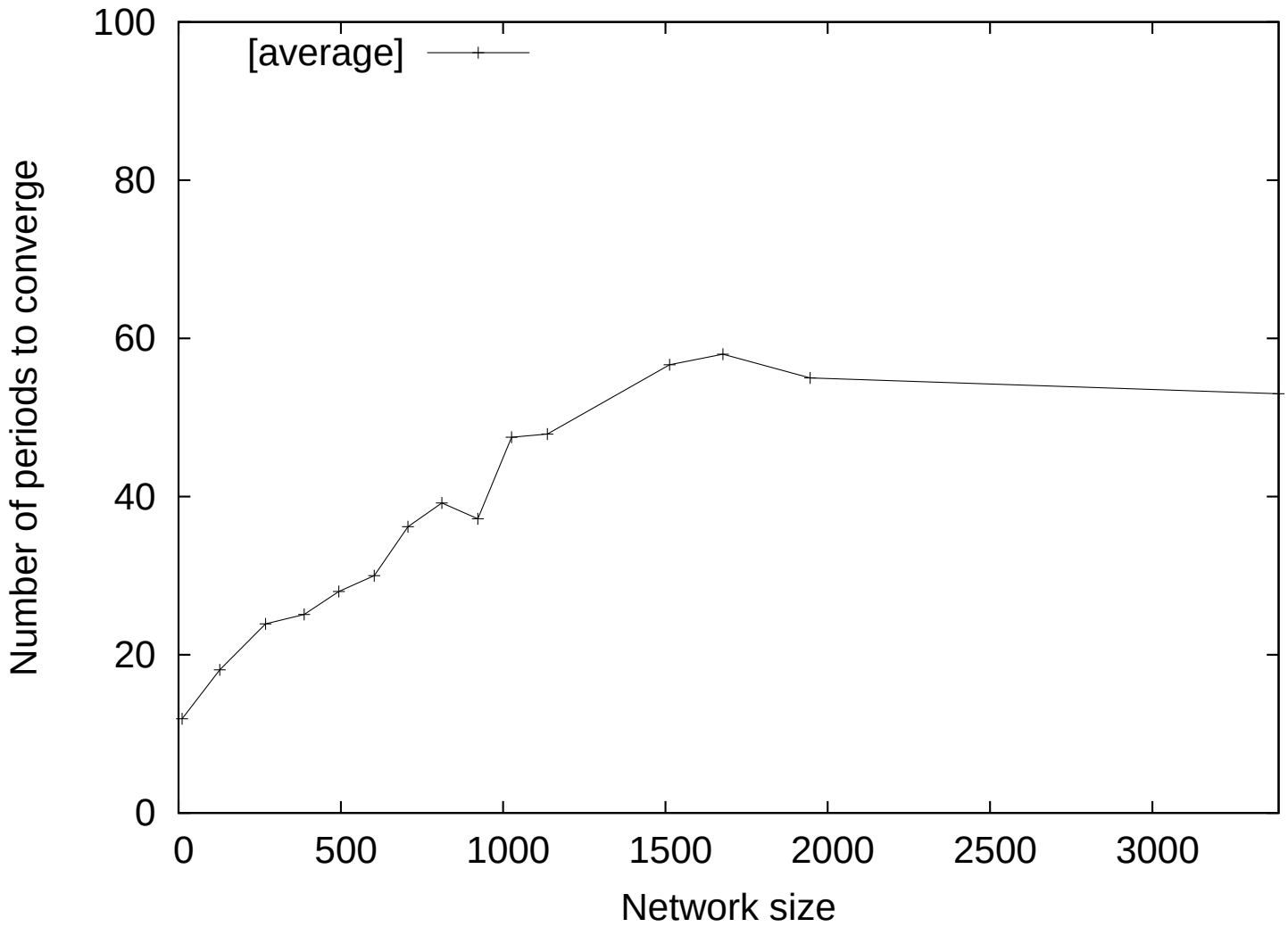
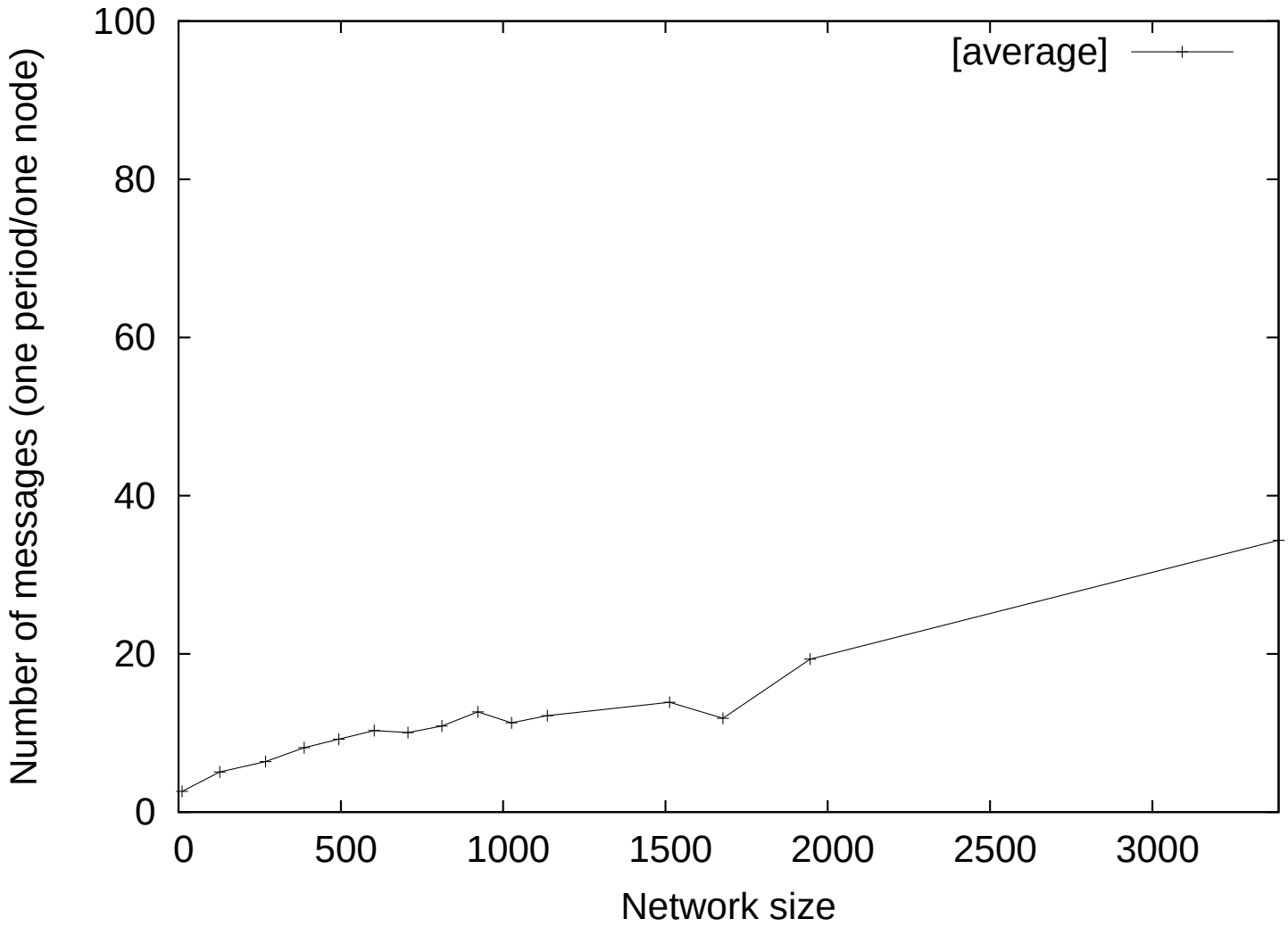
ABEA

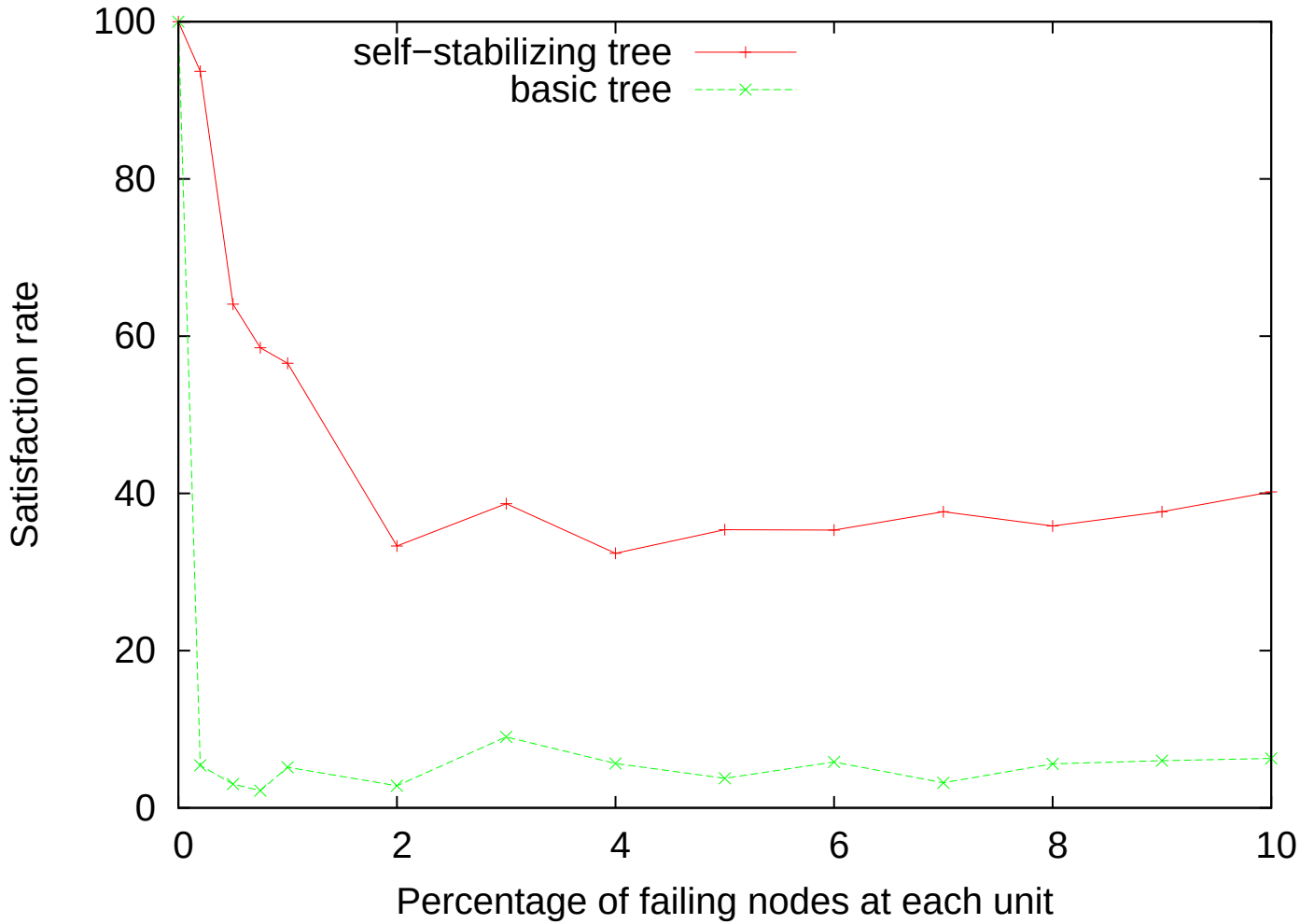
Simulation : Convergence Time



Simulation : Communication Amount



Simulation : Degradation

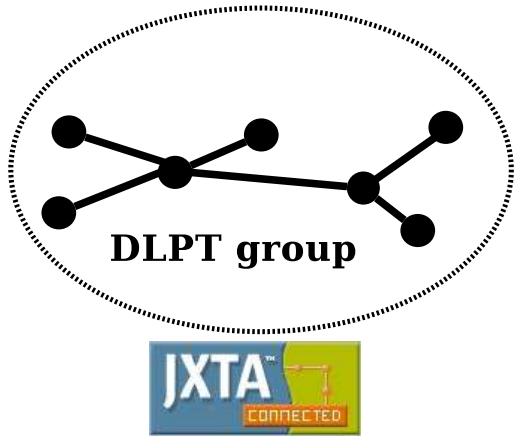


Outline

1. DLPT : a Trie-Based Solution
2. Mapping & Load Balancing
   - Protocol
   - Load Balancing
   - Simulation
3. Fault-tolerance
   - Snap-Stabilizing PGCP Tree (State Model)
   - Self-Stabilizing PGCP Tree (Message-Passing Model)
4. Prototype Implementation
   - Design
   - Early Experiments
5. Summary & Open Problems

Physical Layer

- JXTA-based
- JXTA discovery
- "**DLPT**" JXTA-group



Logical Layer

- Explicit tree topology maintenance
- Random distribution of nodes on peers
- Message in the tree :
  - Serialized communication between JXTA peers
  - JXTA communications

Physical Layer

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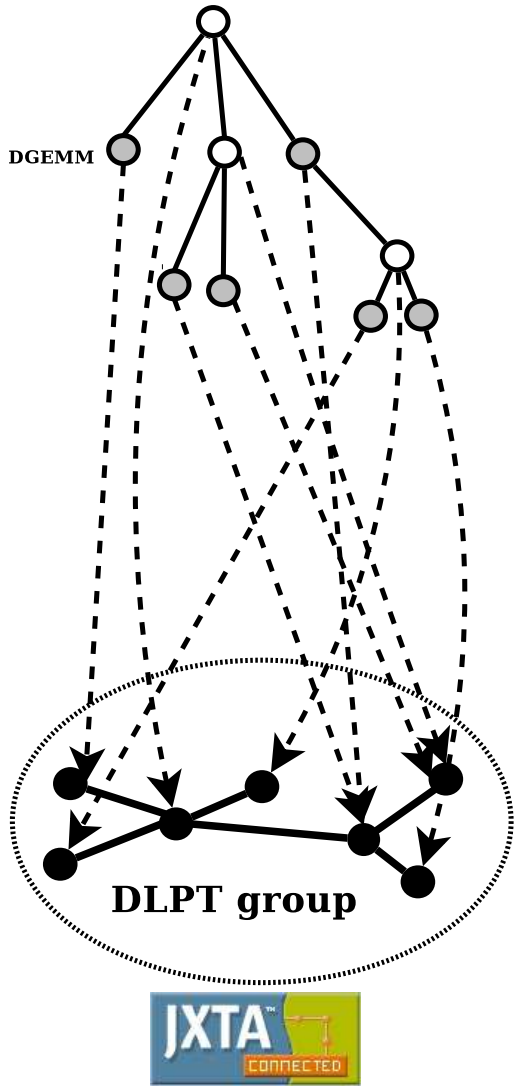
- JXTA discovery
- "**DLPT**" JXTA-group



Experiments : Set-Up

Platform used

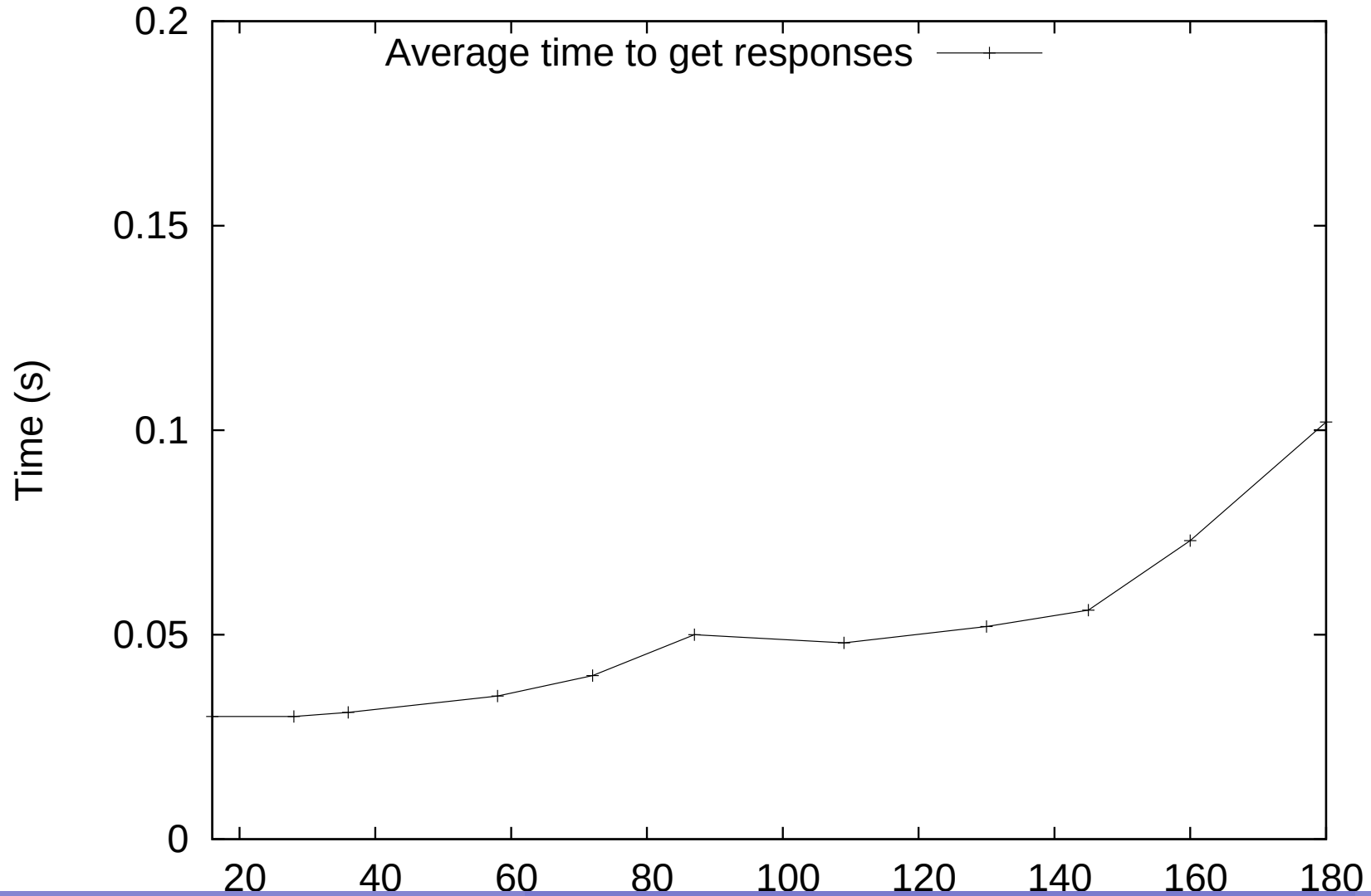
Grid'5000 platform

- `Capricorne` cluster in Lyon
  - 25 nodes (2 x AMD Opteron 246)
  - Gigabit Ethernet (Myrinet-2000 cards)
- `Grelon` cluster in Nancy
  - 60 nodes (2 x Intel Xeon 5110)
  - Gigabit Ethernet (Broadcom BCM5721 cards)

Steps

- Physical deployment
- Simulation of servers (insertion requests)
- Simulation of clients (discovery requests)

Experiments : Capricorne Results



Experiments : `Grelon` Results

Nodes (Services)	Peers	Response time (s)
432 (300)	60	0.105

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Summary

- DLPT
  - A novel P2P-fashioned approach for service discovery
  - Structured and Expressive
- Mapping and load balancing
  - Self-contained architecture
  - Load balancing heuristics
- Fault-tolerance
  - Best-effort alternatives
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  - Two layer architecture implemented
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Hints for Future Work

- Design
  - Topology awareness
  - Optimizations (cache, shortcuts)
- Mapping & Load balancing
  - Coupling our objective function with *K-choices*
  - Analysis results on the clustering obtained
  - Implementation
- Fault-tolerance
  - Snap-stabilization and message-passing
  - Self-stabilization and availability
  - Implementation
- Experiments
  - Load balancing
  - Self-stabilization
  - Larger scale

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Service Discovery : Open Problems

Different kinds of platforms

- Petascale computing
- Research grids
- Desktop computing

Different kinds of volatility

- Failures
- Crashes
- Resources sharing

Thx !