FINAL: Flexible and Scalable Composition of File System Name Spaces

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Background: Single System Image (SSI)

Unified view of distributed system resources

- allow applications to access resources as if local
- simplifies development of applications, tools, and middleware

Examples:

- unified process space: BProc, Clusterproc
- unified file space: Unix United
- distributed operating systems: LOCUS, Sprite, Amoeba, MOSIX, GENESIS, OpenSSI, Kerrighed

TBON-FS: SSI for Group File Operations

TBON-FS client views unified file name space

- constructed from independent file servers
- target: SSI for 10k – 100k servers

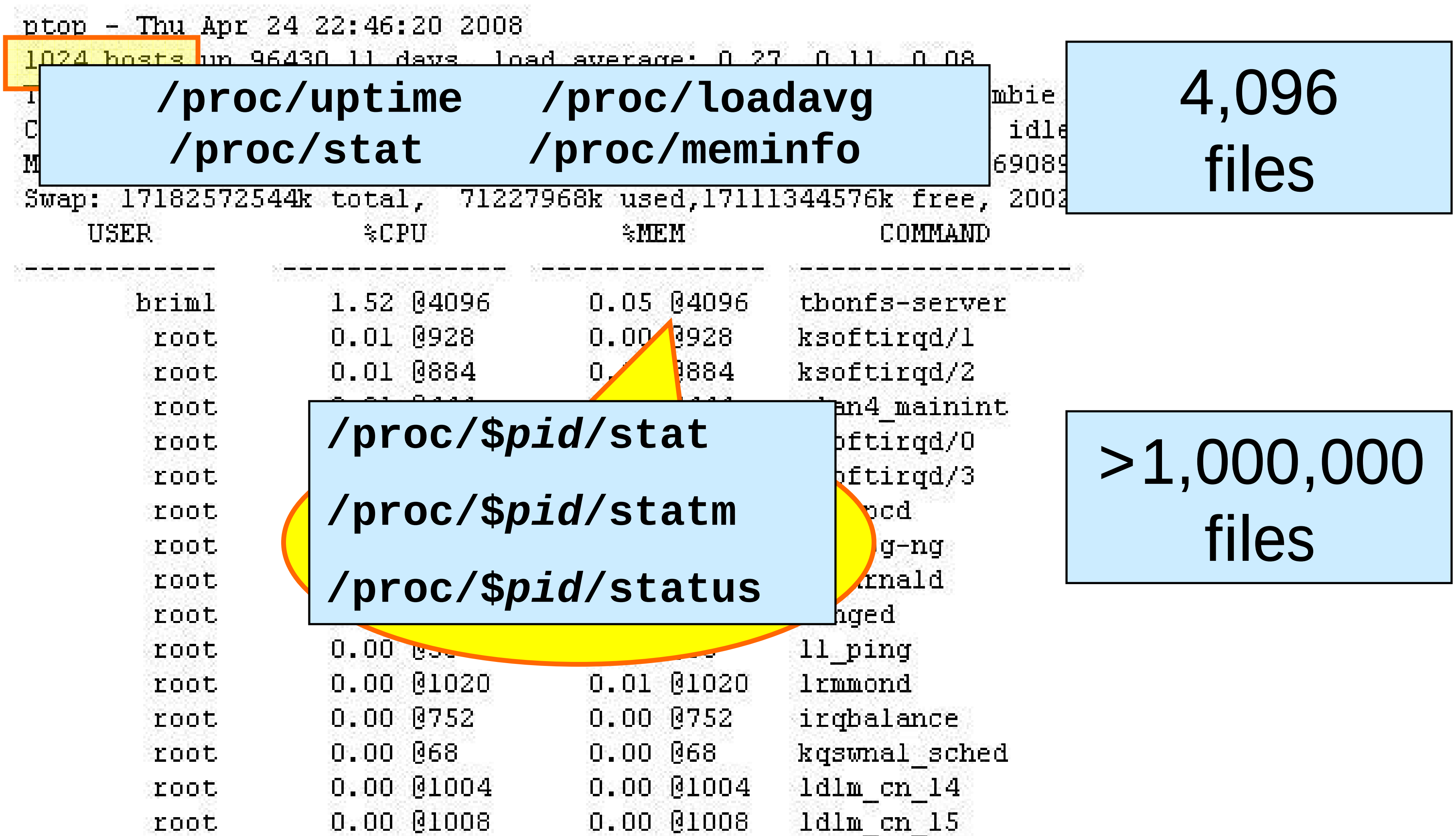
Group file operation idiom: **gopen( )**

- Open files in directory as a group ⇒ **gfd**
- Apply file operations on `gfd` to entire group

TBON-FS employs *Tree-Based Overlay Network*

- provides scalable group file operations via TBON multicast communication and data aggregation

Scalable Distributed Monitoring: ptop



TBON-FS: Problematic Scenario

Prototype used server isolation

- `/tbonfs/$server/…`
- leads to non-scalable group creation

```
mkdir group_dir
foreach member ( /tbonfs/*/path/to/file ) {
    server = …
    symlink $member group_dir/file.$server
}
```

We can do better!!

Custom `ptop` Name Space

Automatic groups:

- host files (4)
- process files (3)

Strategy:

- Create group directories containing files from all hosts/processes

```
/ptop/
     /hosts/
           /loadavg/
                   /host1
                   /…
                   /hostn
           /meminfo/…
           /stat/…
           /uptime/…
     /procs/
           /stat/
                /hostpid1
                /…
                /hostpidn
           /statm/…
           /status/…
```

Goal: Scalable SSI Name Spaces

Let clients specify name space

- name space suited for client needs
- *automatic creation* of natural groups
- easy creation of custom groups

Efficient, distributed name space composition

- avoid traditional SSI scalability barriers of centralization or consensus

Name Space Composition @ Scale

Lots of prior work in name space composition

- mounts and union mounts
- private name spaces for custom views & security
- global name spaces that aggregate resources

Ill-suited to composing 10k – 100k spaces

- inefficient composition
  - pair-wise operations (e.g., mount)
  - fine-grained directory entry manipulation
- inflexible structure and semantics

Desired Composition Properties

Flexibility: describe a wide range of compositions

Clarity: simple, intuitive semantics

Efficiency & Scalability:

- avoid centralized, pair-wise composition
- use TBON for distributed composition

File Name space Aggregation Language

Two primary abstractions

1. Tree: a file name space
2. File Service: access to local/remote file system(s)

A set of tree composition operations

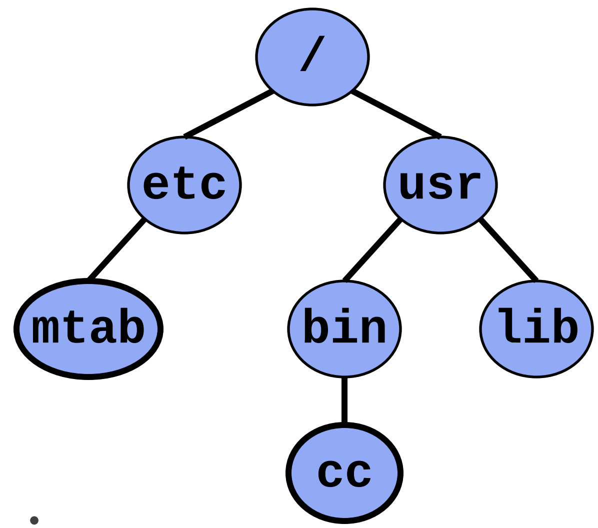
- get or prune a sub-tree
- path extend a tree
- combine two or more trees

FINAL Abstractions: Tree

Assume name spaces are traditional directory trees

Name Space Abstraction

- rooted tree of named vertices
- edges for parent dir, children



Tree is essentially a name space *view*

- independent of underlying file service name spaces
  - each vertex associated with `(service, path)`
- views are immutable

FINAL Abstractions: File Service

File service provides:

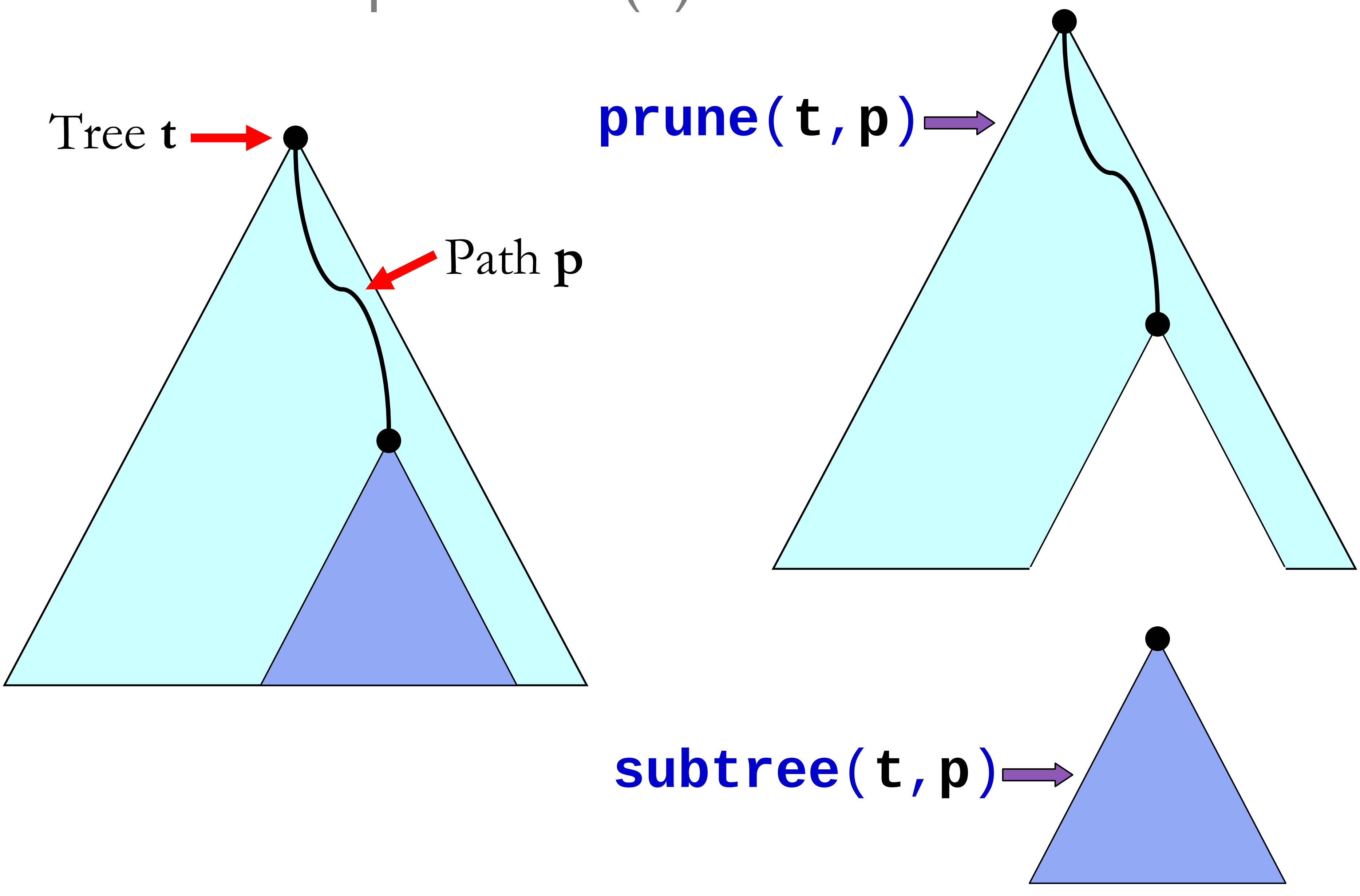
- access to a physical name space
- operations on files in that name space
    - e.g., `stat()`, `open()`, `read()`, `write()`, `lseek()`

Define service instance by name, returns snapshot view

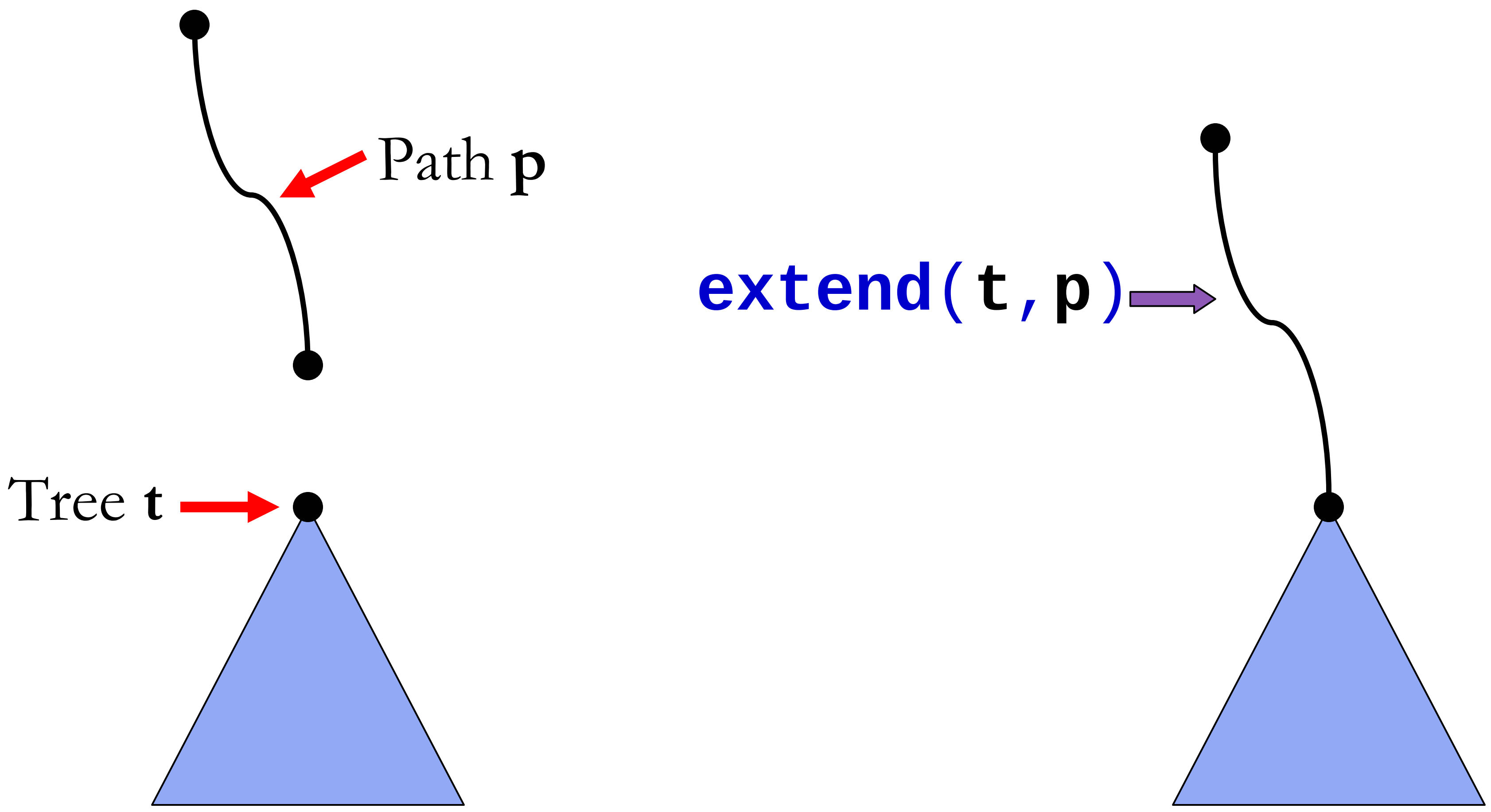
- key-value pairs for service options
- Examples:

```
local()
nfs( host=server, mount=path )
9P( srv=file, mount=path )
```

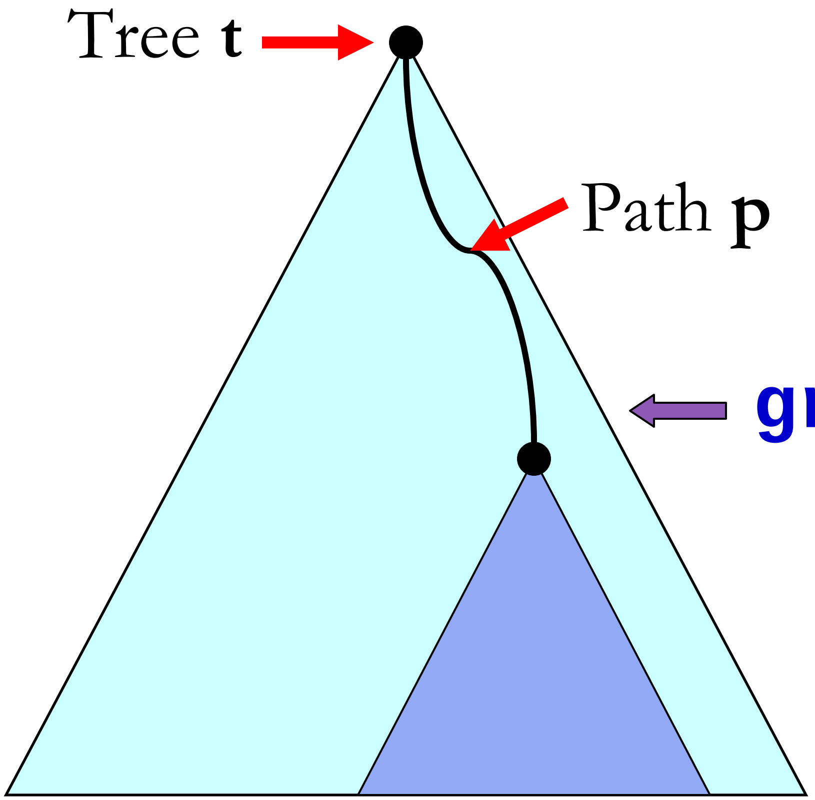
FINAL Path Operations (1)



FINAL Path Operations (2)



FINAL Composition Operations (1)

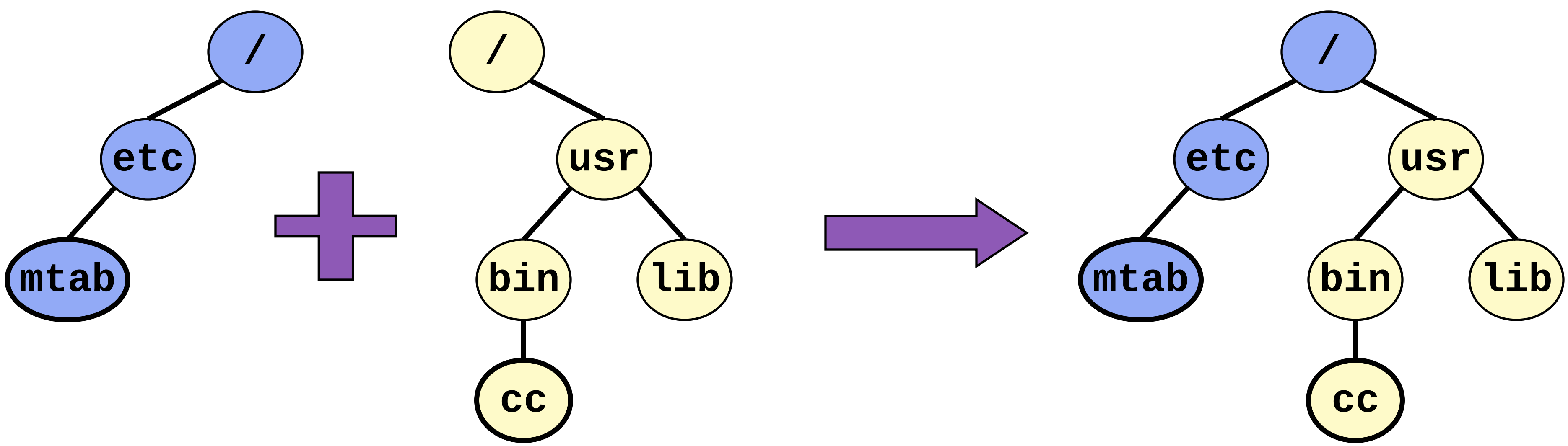



```
graft( prune(t,p),
       subtree(t,p),
       p )
```

FINAL Composition Operations (2)

`merge( {Tree_k}, conflict_fn )`

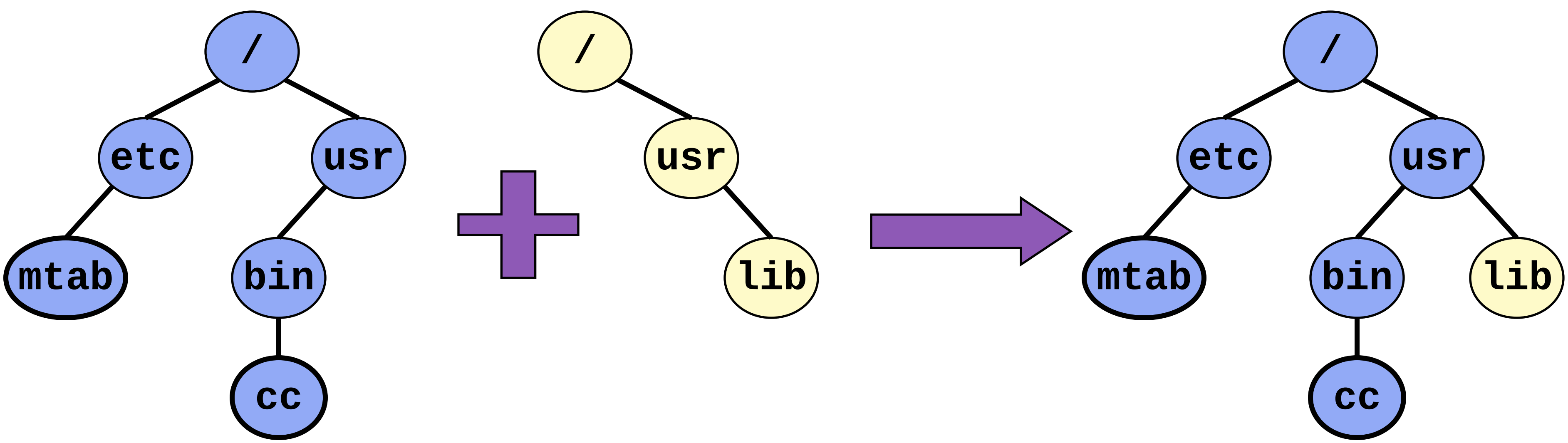
- Deep merge of all trees in input set
- Conflict function called with vertices sharing same path, returns vertices to add to result tree



FINAL Composition Operations (3)

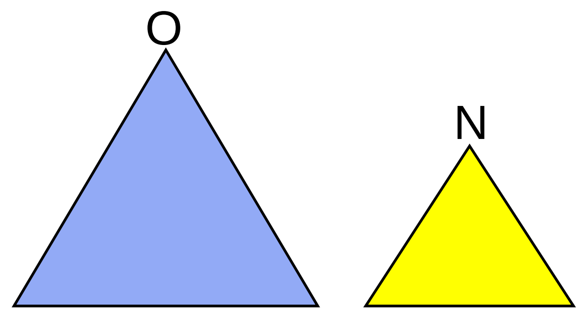
$$\texttt{merge(\{Tree}_k\texttt{\}, overlay)}$$

- Precedence to first tree containing shared path



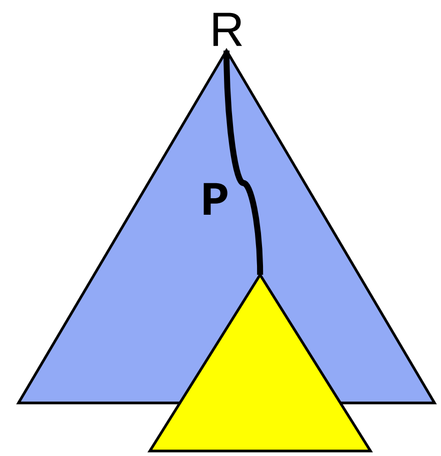
Composition Examples: OS mounts

O : original name space
N : new file system name space
R : result name space



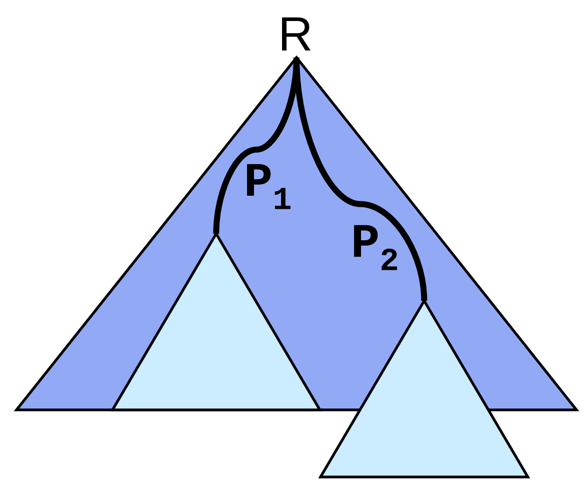
- Standard mount
  - replace sub-tree at path P

```
R = graft( prune(O,P), N, P )
```



- Bind mount
  - make sub-tree at path P_1 also visible at P_2

$$R = \mathtt{graft}(\ \mathtt{prune}(O,P_2),\ \mathtt{subtree}(O,P_1),\ P_2\ )$$



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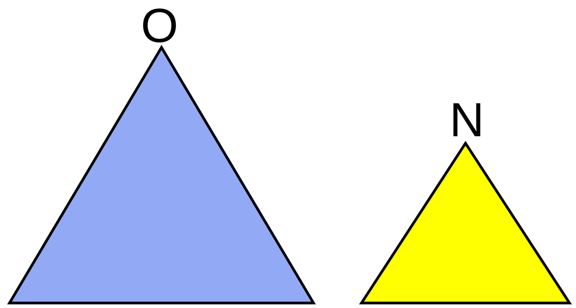
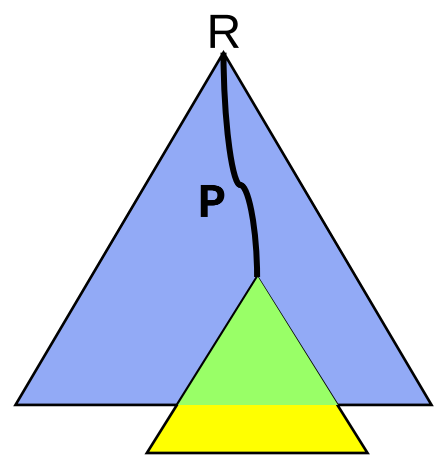


- Union mount
  - lay N over sub-tree at path P

```
R = graft( prune(O,P),
           merge({subtree(O,P),N},
                 overlay),
           P )
```



TBON-FS + FINAL

Client mounts views of TBON-FS service

```
graft( local(), tbonfs_svc(final_spec), mountpt )
```

TBON-FS service

- `merge()` all server name spaces
  - conflict function currently hard-coded
- each server name space constructed from FINAL specification given by client
  - specs can depend on local context
  - results in similar name spaces across servers

Example: Automatic File Groups

Client FINAL

```
T = tbonfs_svc(hosts,
               srv_final)
root = graft(local(), T,
             "/tbonfs/config")
```

Server FINAL

```
E = subtree(local(),"/etc")
G = subtree(E,"/group")
P = subtree(E,"/passwd")
GP = merge({G,P},overlay)
root = GP
```

```
/tbonfs/
       /config/
              /group/
                    /host1
                    /…
                    /hostn
              /passwd/
                     /host1
                     /…
                     /hostn
```

Example: Server-local Context

- Handle heterogeneity across servers by hiding name space differences
- Ex: Batch Job System
  - temporary file staging area

Server FINAL

```
T = subtree(local(), "/tmp")
if( T == NULL )
  T = subtree(local(),
              "/scratch")
if( T == NULL )
  T = subtree(local(),
              getenv(HOME))
root = extend(T,"/tmp")
```

```
/tbonfs/
        /tmp/...
```

Example: Cloud Management

- Group distributed hosts by resources provided
  - OS version and CPU type
  - Resource amounts
    - Disk, Memory, # CPUs

<u>Server FINAL</u>

```
L = local()
os = getenv(OSTYPE)
arch = getenv(MACHTYPE)
OA = extend(L, “/$os/$arch”)
root = OA
```

```
/cloud/
      /Linux/
            /x86/
                /path/
                     /host_i
                     /…
                     /host_k
            /x86_64/…
            /ppc32/…
            /ppc64/…
      /WinXP/$arch/…
      /Win7/$arch/…
```

Performance Considerations

Improving efficiency of FINAL operations

- immutable view semantics imply tree copies
  - views implemented as versioned trees
- deep merges can be costly
  - lazy evaluation of specifications as new paths are accessed

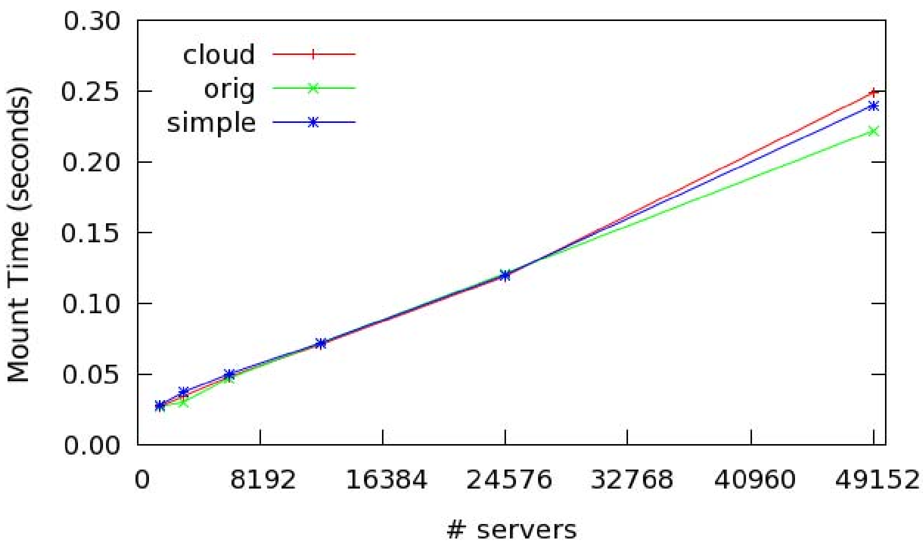
TBON-FS name space caching

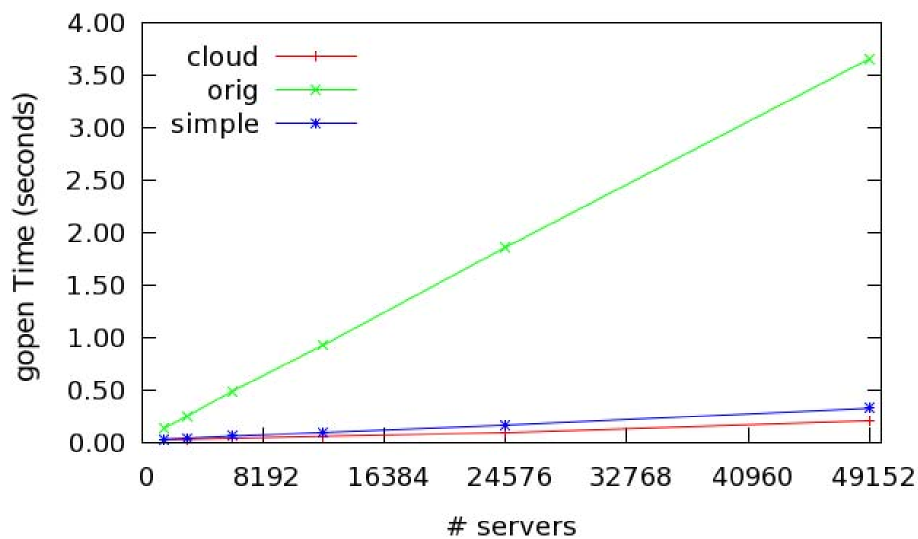
- client only has mount paths
- servers cache accessed portion of name space
- potential for improved lookup latency through caching of merged name space within TBON

Performance Evaluation

Measured:

1. Time to construct name space @ mount
2. Time to gopen( )
3. Effect on group file ops → none, as expected





Conclusion

TBON-FS targets SSI for 10k – 100k servers

FINAL provides *flexibility* to customize name space

- helps improve efficiency of file group definition

FINAL compositions are *scalable*

- use trees to compose trees
- server name spaces constructed in parallel