Remote I/O in Condor

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Outline

- **Introduction**
- Using Remote I/O
- Under the Hood
- Build Your Own: Bypass
- Conclusion

Introduction

- The National Technology Grid provides you with access to a diverse array of machines.
- Although you have permission to use these machines, they may be unfriendly to your application.

Introduction (Cont.)

- Remote I/O is an adapter which provides a friendly execution environment on an unfriendly machine.
- Condor uses remote I/O to homogenize the many machines in a Condor pool.
- Can we adapt this to the Grid?

What is Unfriendly?

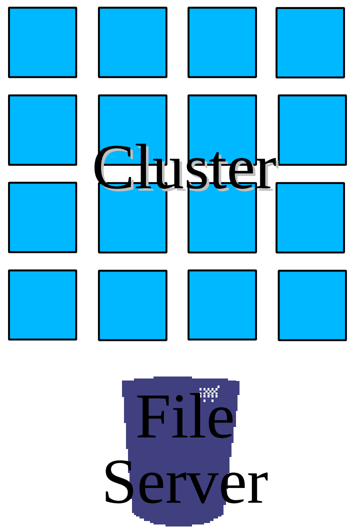
- Programs can technically execute:
  - Correct CPU and OS and enough memory
- But missing some critical items:
  - No input files.
  - No space for output files.
  - No shared filesystem.
  - No login - run as "nobody"?

Range of Unfriendliness

- Anonymous compute node on the Grid:
  - Run as "nobody", with no access to disk.
- Machine at other institution:
  - Can login, have some disk, but no file system.
- Machine down the hall:
  - Can login, share one NFS mount, but not another.

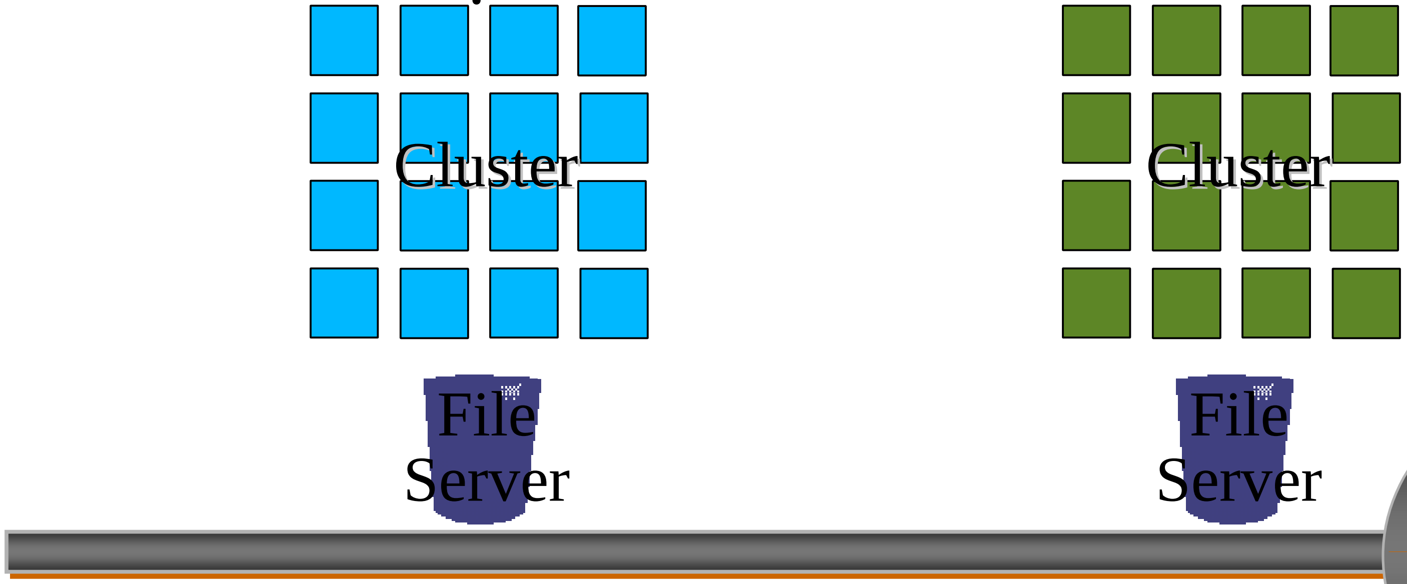
Why use an unfriendly machine?

- After all, homogeneous clusters are the norm:
  - 10s or 100s of identical machines.
  - Centrally administrated.
  - Shared filesystem



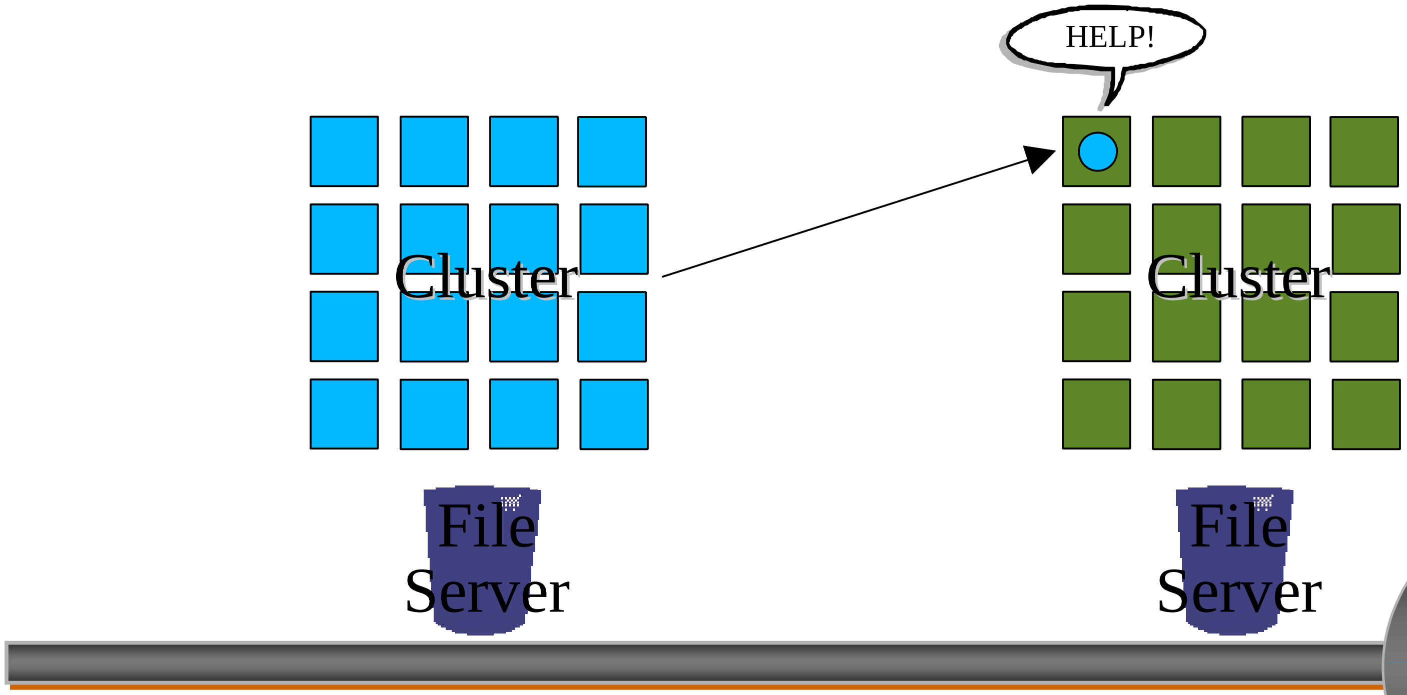
Need more machines!

- Another hundred idle machines could be found across the street or in the next department..



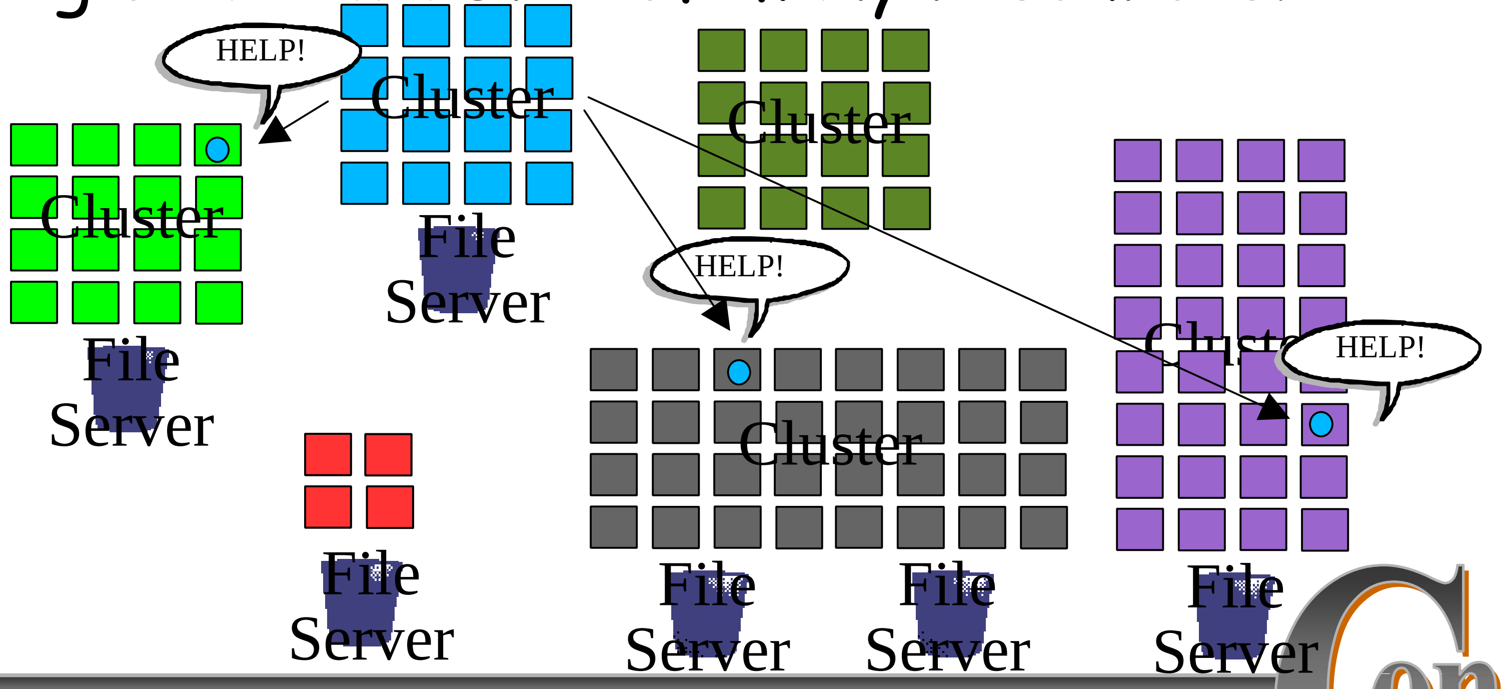
Need more machines! (Cont.)

- But, your application may not find the resources it needs.



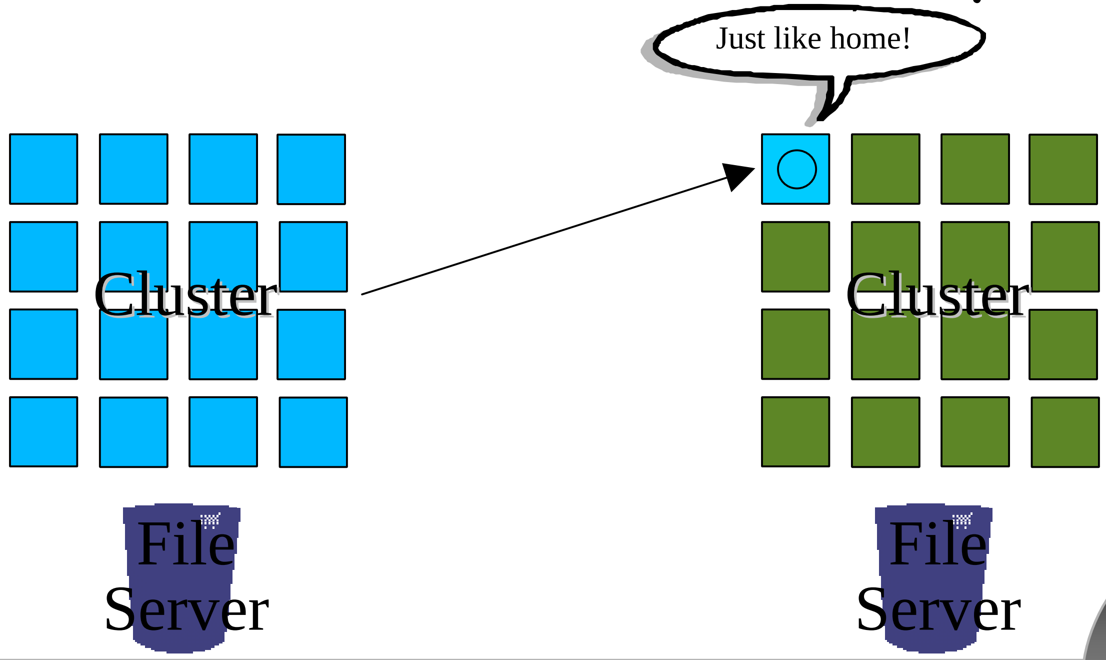
Need more machines! (Cont.)

- The problem is worse when we consider a global data Grid of many resources!



Solution: Remote I/O

- Condor remote I/O creates a friendly environment on an unfriendly machine.



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Using Remote I/O

- Condor provides several "universes":
  - Vanilla - UNIX jobs + do not need remote I/O
  - Standard - UNIX jobs + remote I/O
  - Scheduler - UNIX job on home machine
  - Globus - UNIX jobs -> Globus
  - PVM - specialized PVM jobs

Vanilla Universe

- Submit any sort of UNIX program to the Condor system.
- Pros:
  - No relinking required.
  - Any program at all, including
    - Binaries
    - Shell scripts
    - Interpreted programs (java, perl)
    - Multiple processes

Vanilla Universe (Cont.)

- Cons:
  - No checkpointing.
  - Very limited remote I/O services.
    - Specify input files explicitly.
    - Specify output files explicitly.
  - Condor will refuse to start a vanilla job on a machine that is unfriendly.
    - ClassAds: FilesystemDomain and UIDDomain

Standard Universe

- Submit a specially-linked UNIX application to the Condor system.
- Pros:
  - Checkpointing
  - Remote I/O services:
    - Friendly environment anywhere in the world.
    - Data buffering and staging.
    - I/O performance feedback.
    - User remapping of data sources.

Standard Universe (Cont.)

- Cons:
  - Must statically link with Condor library.
  - Limited class of applications:
    - Single-process UNIX binaries.
    - A number of system calls prohibited.

System Call Limitations

- Standard universe does not allow:
  - Multiple processes:
    - fork(), exec(), system()
  - Inter-process communication:
    - semaphores, messages, shared memory
  - Complex I/O:
    - mmap(), select(), poll(), non-blocking I/O, file locking

System Call Limitations (Cont.)

- Standard universe also does not allow:
  - Kernel-level threads.
- Too restrictive? Try the vanilla universe.

System Call Features

- The standard universe does allow:
  - Signals
    - But, Condor reserves SIGTSTP and SIGUSR1.
  - Sockets
    - Keep it brief - network connections, by nature, cannot migrate or checkpoint.

System Call Features (Cont.)

- The standard universe does allow:
  - Complex I/O on sockets
    - select(), poll(), and non-blocking I/O can be used on sockets, but not other sorts of files.
  - User-level threads

What Universe?

- Vanilla:
  - Perfect for a Condor pool of identical machines.
- Standard:
  - Needed for heterogeneous Condor pools, flocked pools, and more generally, unfriendly machines on the Grid.
- The rest of this talk concerns the standard universe.

Using the Standard Universe

- Link with Condor library.
- Submit the job.
- Get brief I/O feedback while running.
- Get complete I/O feedback when done.
- If needed, remap files.

Link with Condor Library

- Simply use condor_compile in front of your normal link line.
- For example,

```
gcc main.o utils.o -o program
```

- Becomes:

```
condor_compile gcc main.o utils.o -o program
```

- Despite the name, only re-linking is required, not re-compiling.

Submit Job

- Create a submit file:

```
% vi program.submit
```

```
Universe = standard

input = program.in
output = program.out

executable = program

queue 3
```

- Submit the job:

```
% condor_submit program.submit
```

Brief I/O Summary

```
% condor_q -io

-- Schedd: c01.cs.wisc.edu : <128.105.146.101:2016>
ID       OWNER        READ     WRITE     SEEK     XPUT      BUFSIZE  BLKSIZE
756.15   joe      244.9 KB 379.8 KB       71   1.3 KB/s 512.0 KB  32.0 KB
758.24   joe      198.8 KB 219.5 KB       78  45.0 B /s 512.0 KB  32.0 KB
758.26   joe       44.7 KB  22.1 KB     2727  13.0 B /s 512.0 KB  32.0 KB

3 jobs; 0 idle, 3 running, 0 held
```

Complete I/O Summary in Email

```
Your condor job "/usr/joe/records.remote input output" exited
with status 0.

Total I/O:
     104.2 KB/s effective throughput
     5 files opened
     104 reads totaling 411.0 KB
     316 writes totaling 1.2 MB
     102 seeks

I/O by File:

buffered file /usr/joe/output
     opened 2 times
     4 reads totaling 12.4 KB
     4 writes totaling 12.4 KB

buffered file /usr/joe/input
     opened 2 times
     100 reads totaling 398.6 KB
     311 write totaling 1.2 MB
     101 seeks
```

Complete I/O Summary in Email

- The summary helps identify performance problems. Even advanced users don't know *exactly* how their programs and libraries operate.

Complete I/O Summary in Email (Cont.)

- Example:
  - CMS - physics analysis program.
  - "Why is this job so slow?"
  - Data summary: read 250 MB from 20 MB file.
  - Very high SEEK total -> random access.
  - Solution: Increase data buffer to 20 MB.

Buffer Parameters

- By default:
  - buffer_size = 524288 (512 KB)
  - buffer_block_size = 32768 (32 KB)
- Change parameters in submit file:
  - buffer_size = 20000000
  - buffer_block_size = 32768

If Needed, Remap Files

- Suppose the program is hard-coded to open `datafile`, but you want each instance to get a slightly different copy. In the submit file, add:

```
file_remaps = "datafile = /usr/joe.data.$(PROCESS)"
```

- Process one gets

```
/usr/joe.data.1
```

- Process two gets

```
/usr/joe.data.2
```

- And so on...

If Needed, Remap Files (Cont.)

- The same syntax will allows the user to direct the application to other third-party data sources such as web servers:

```
file_remaps = "datafile =
   http://www.cs.wisc.edu/usr/joe/data”
```

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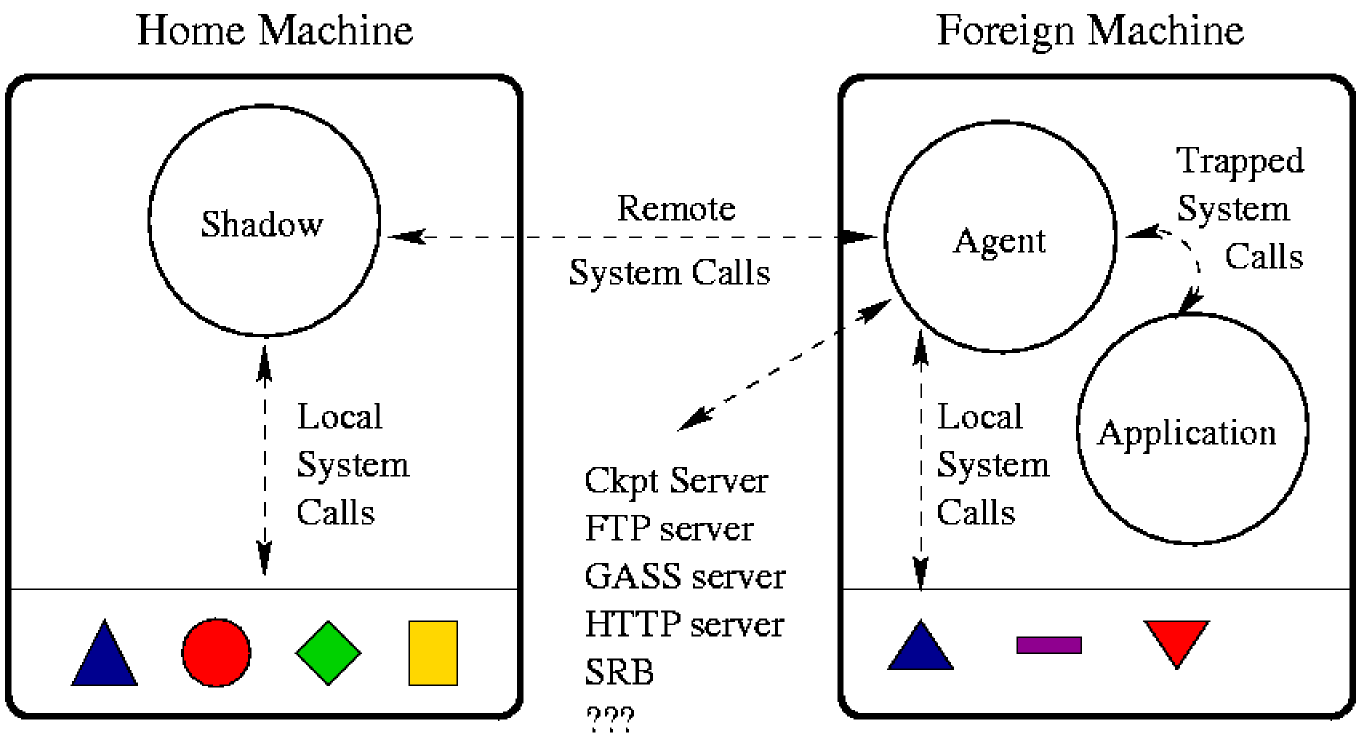
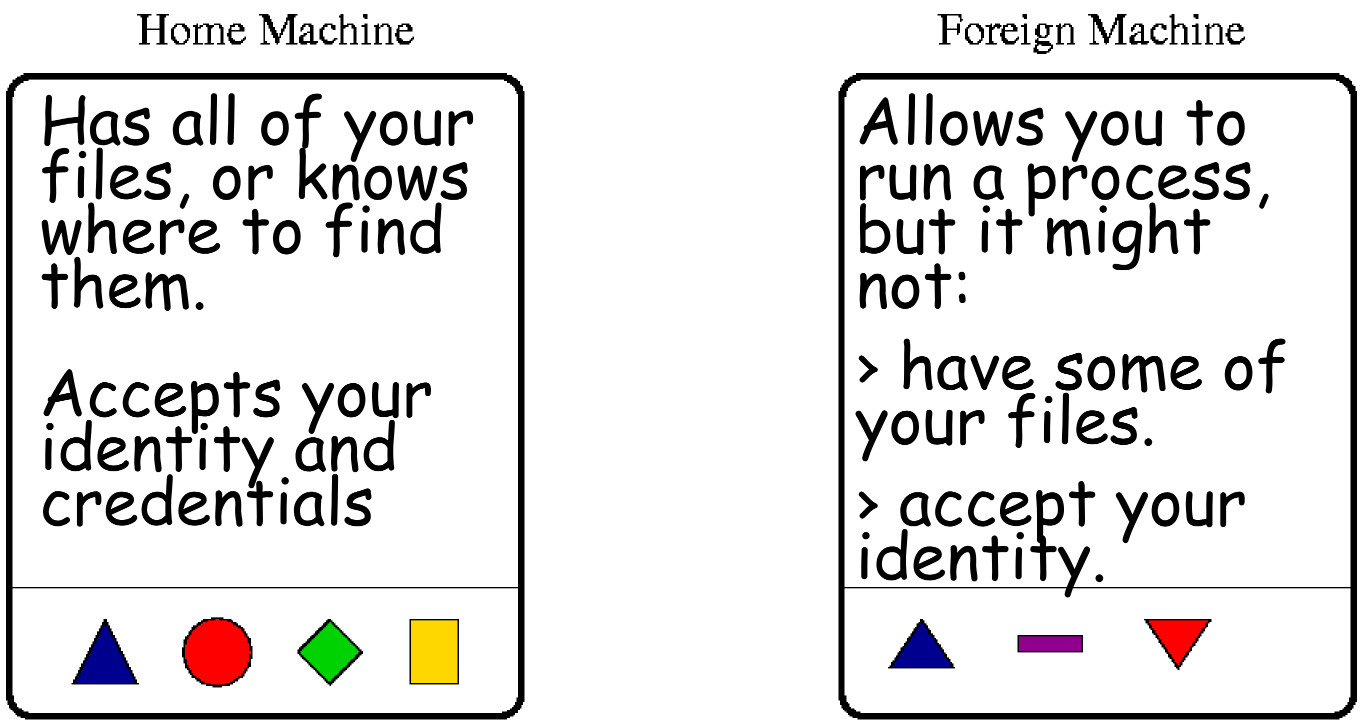
The Big Picture



The Machines



Home Machine

Has all of your files, or knows where to find them.

Accepts your identity and credentials

Foreign Machine

Allows you to run a process, but it might not:

› have some of your files.

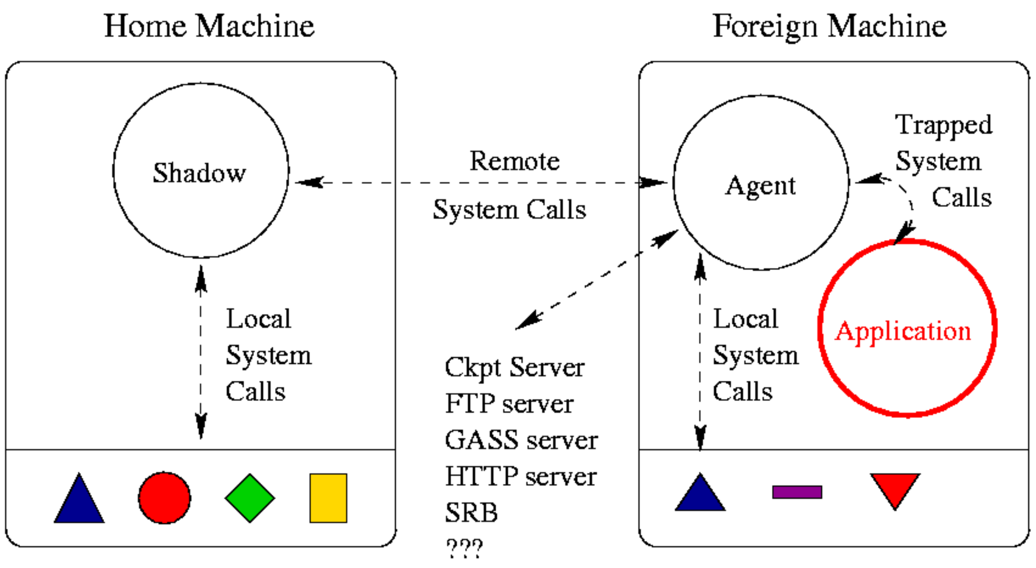
› accept your identity.

General Strategy

- Trap all the application's I/O operations.
  - open(), close(), read(), write(), seek(), …
- Route them to the right service (at the shadow's direction)
- Cache both service decisions and actual data.

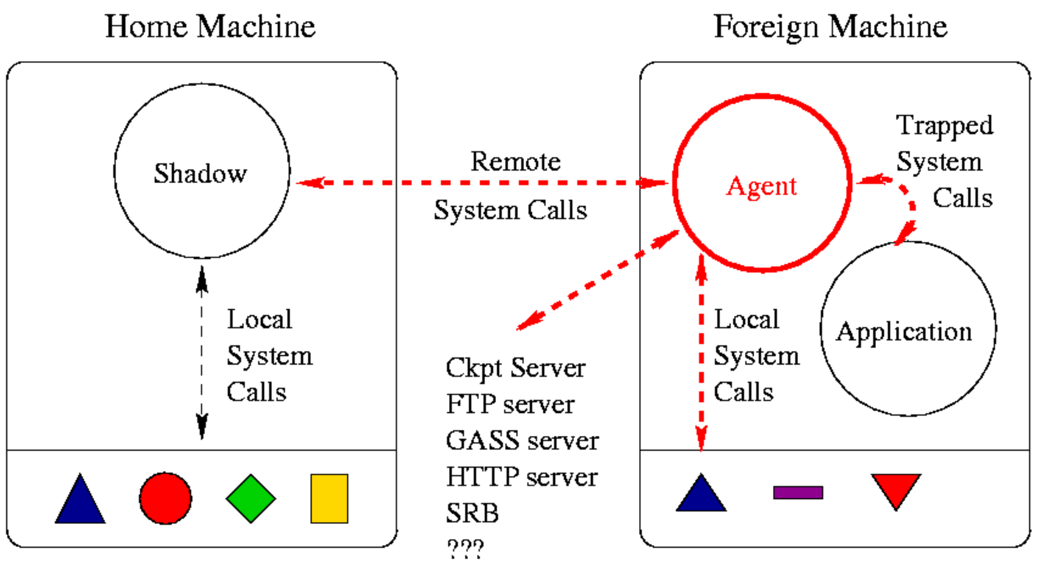
Application

- Plain UNIX program.
- Unaware that it is part of a distributed system.
- Statically linked against Condor library.



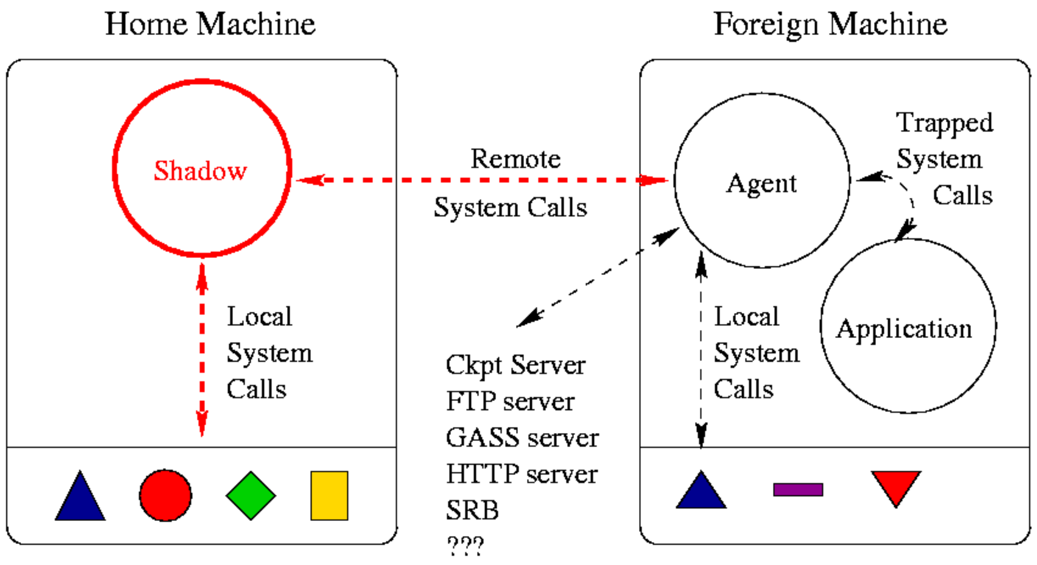
Condor Library

- Sends system calls to various services via RPC.
- Buffers and stages data.
- Asks shadow for policy decisions.

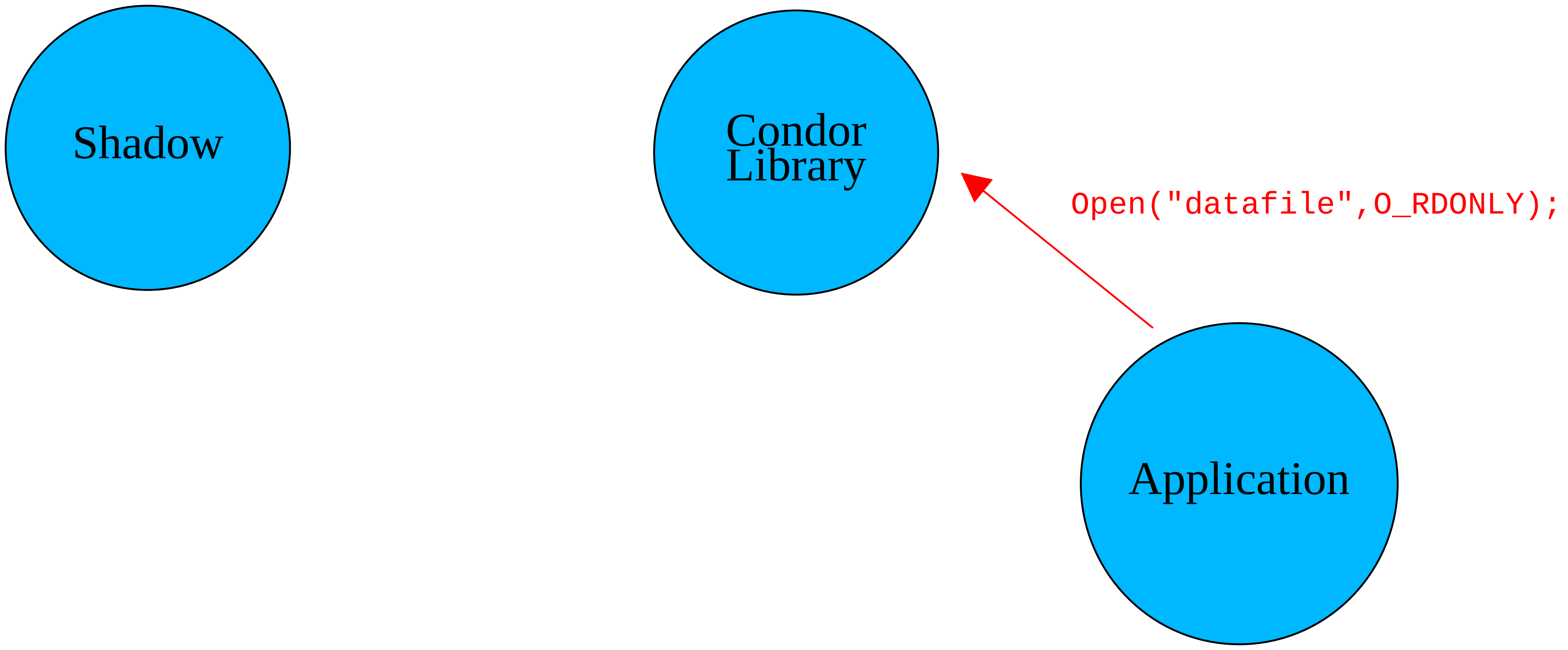


Shadow

- Makes policy decisions for application.
- Executes remote system calls for application.



Opening a File



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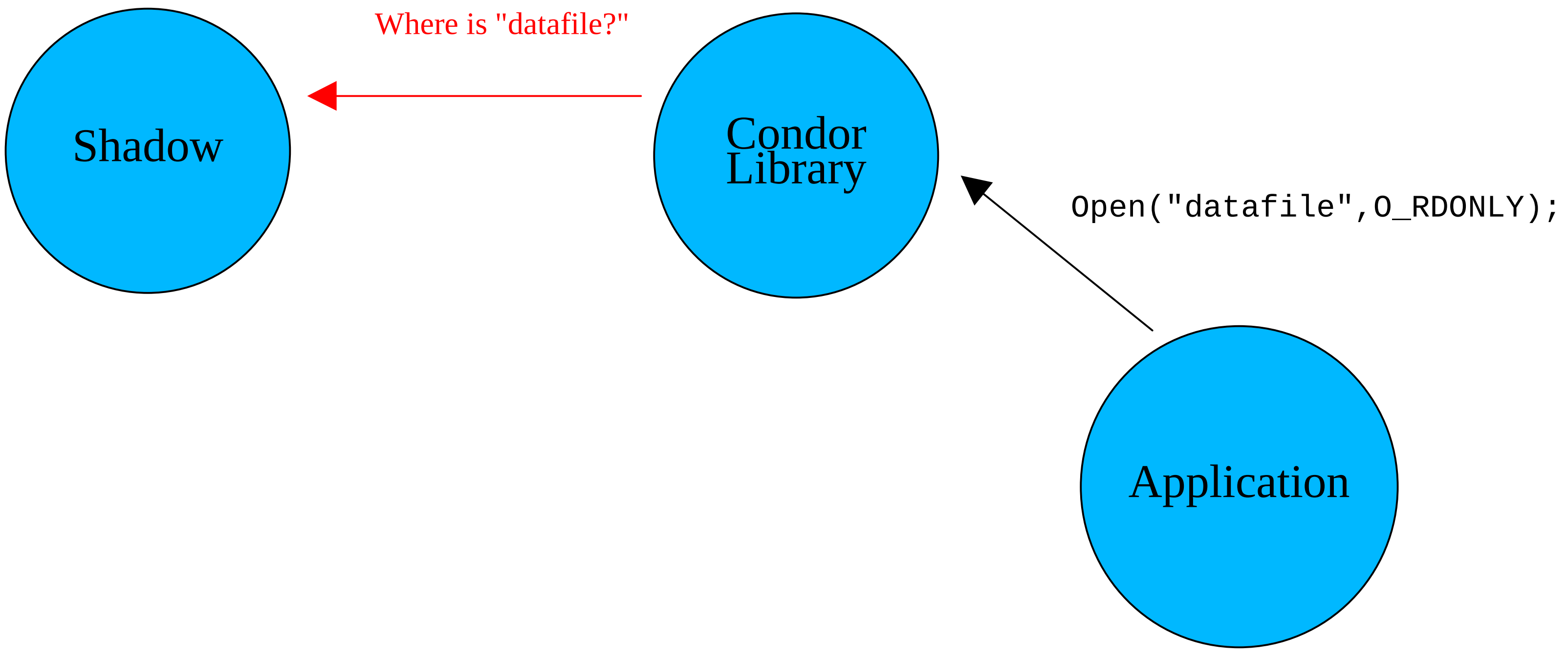

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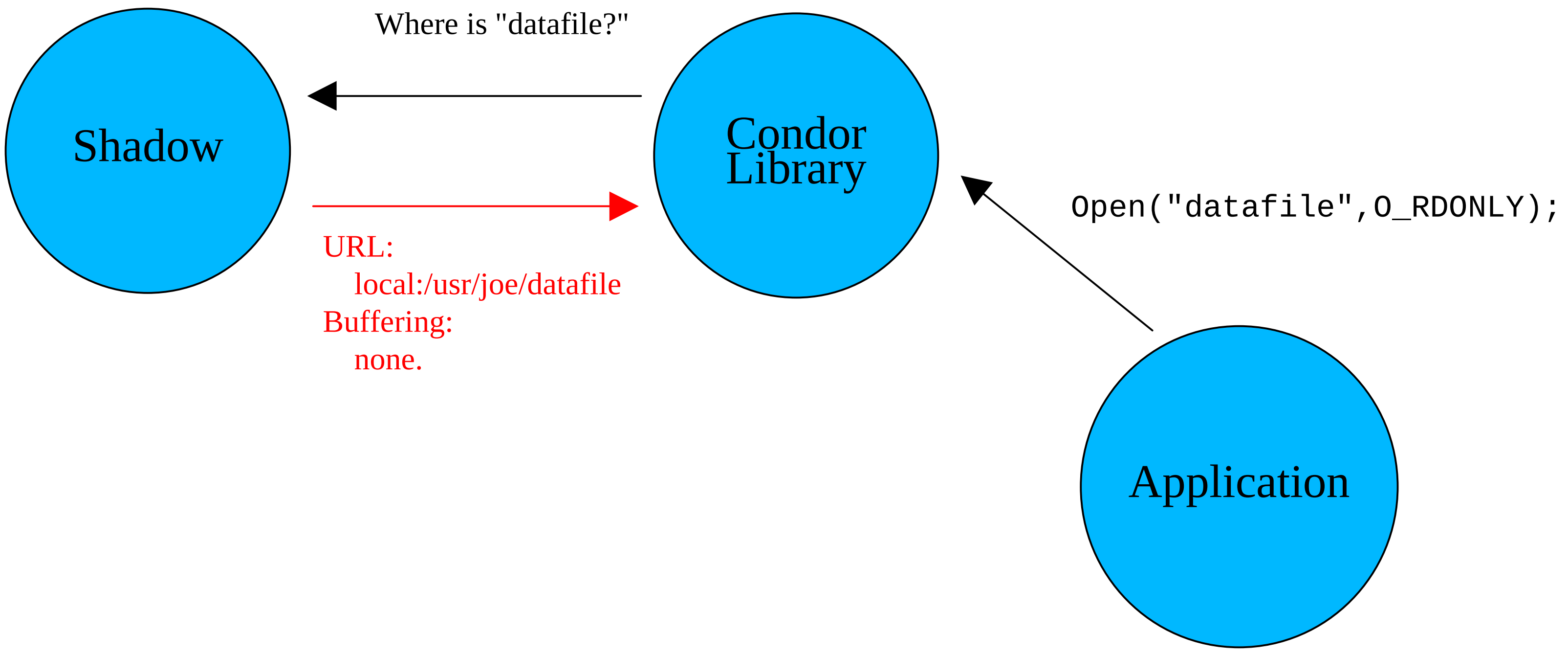

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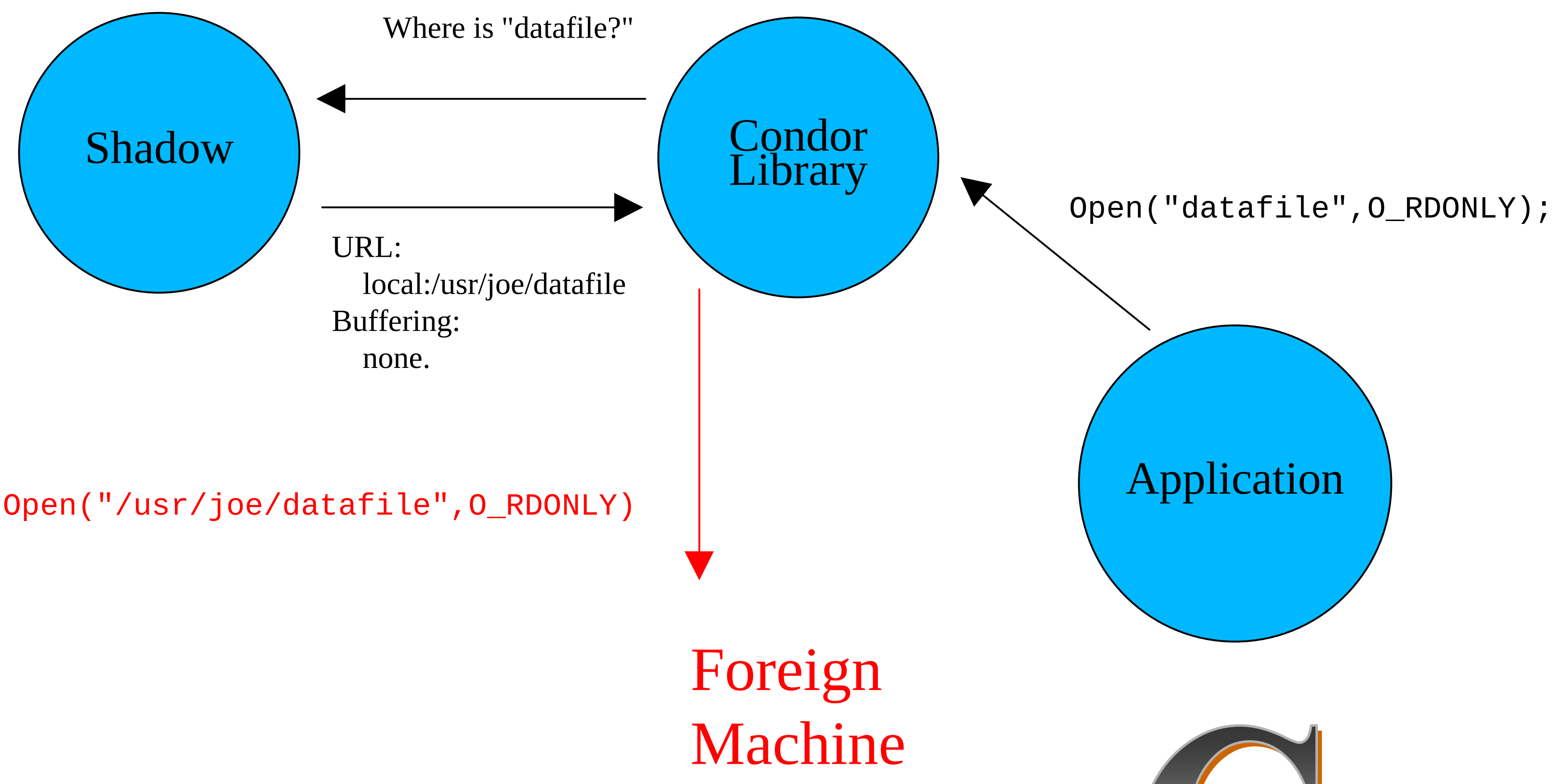
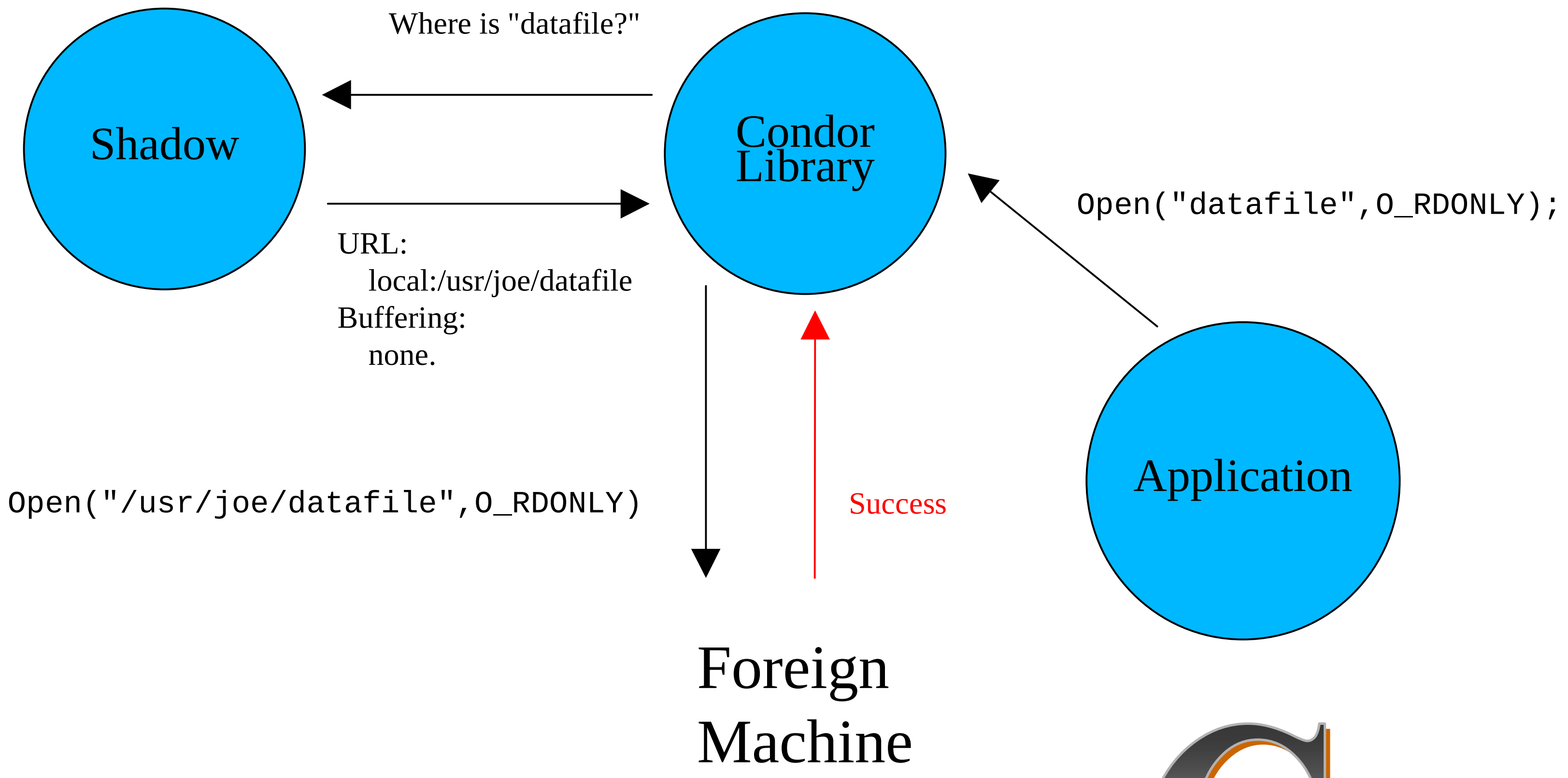
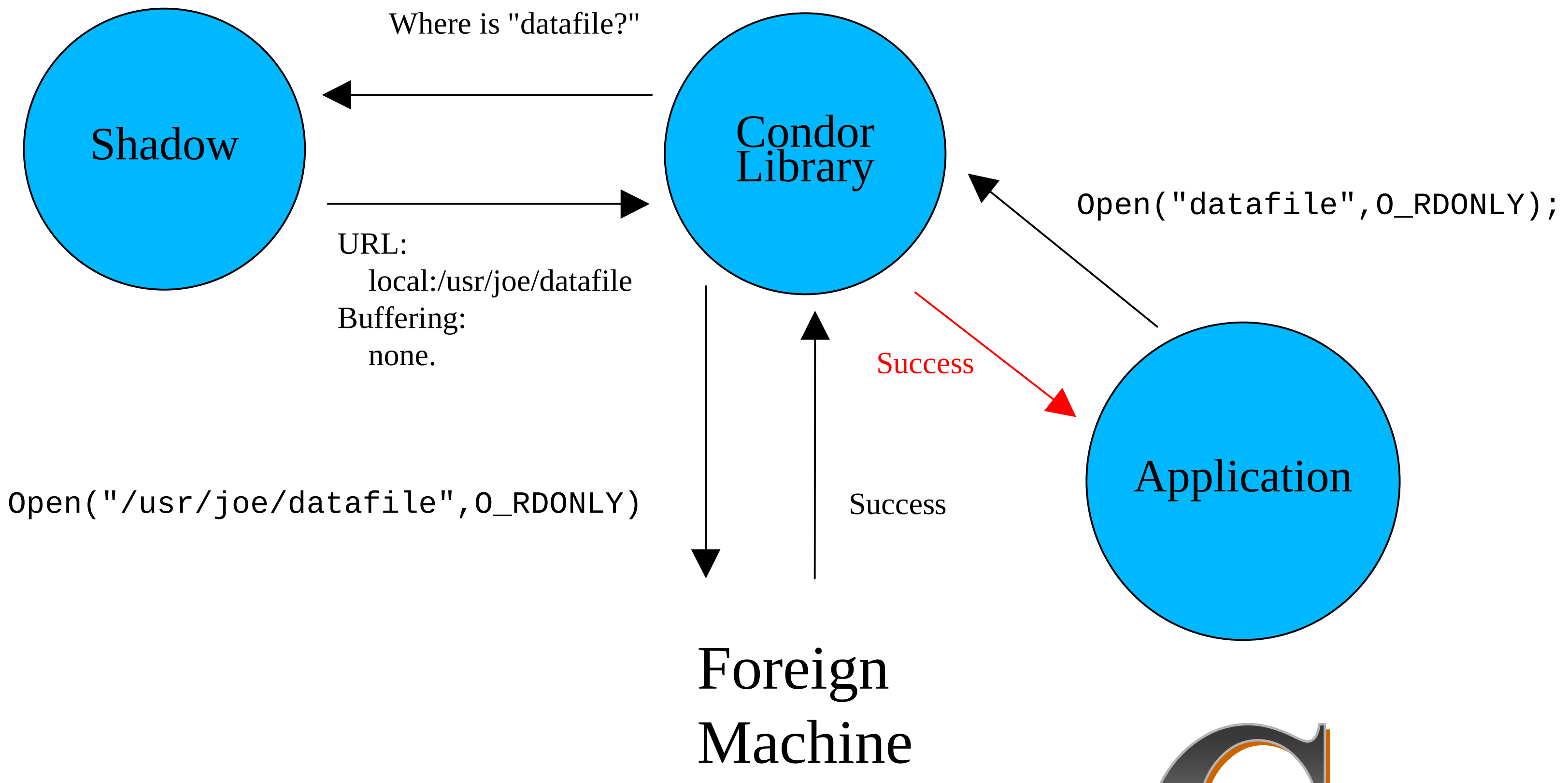


Opening a File



Opening a File



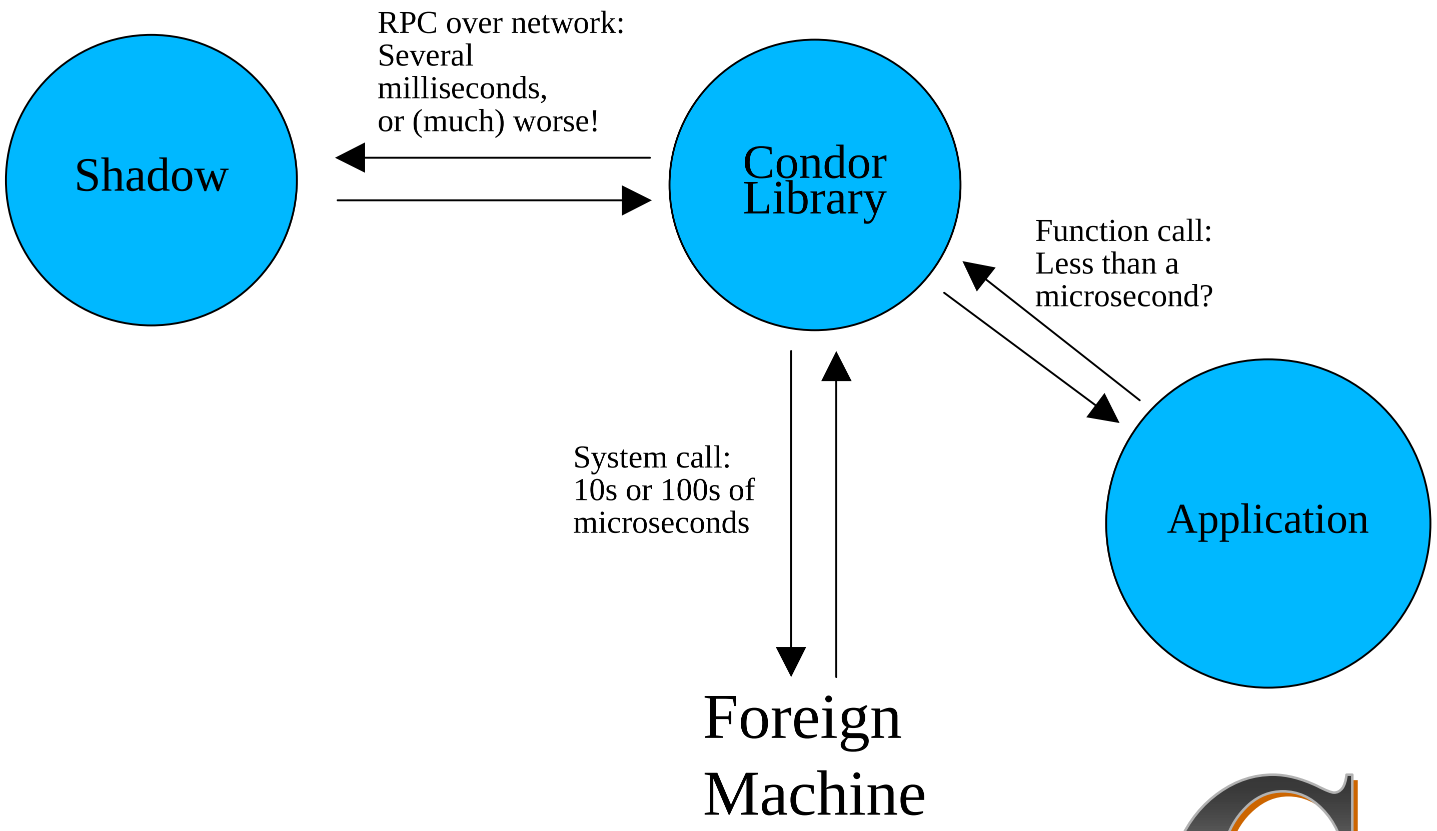
Shadow Responses

- URL:
  - remote: Use remote system calls.
  - local: Use local system calls.
  - special: Use local system calls, disable checkpointing.
  - http: Fetch from a web server.
  - Others in development…

Shadow Responses (Cont.)

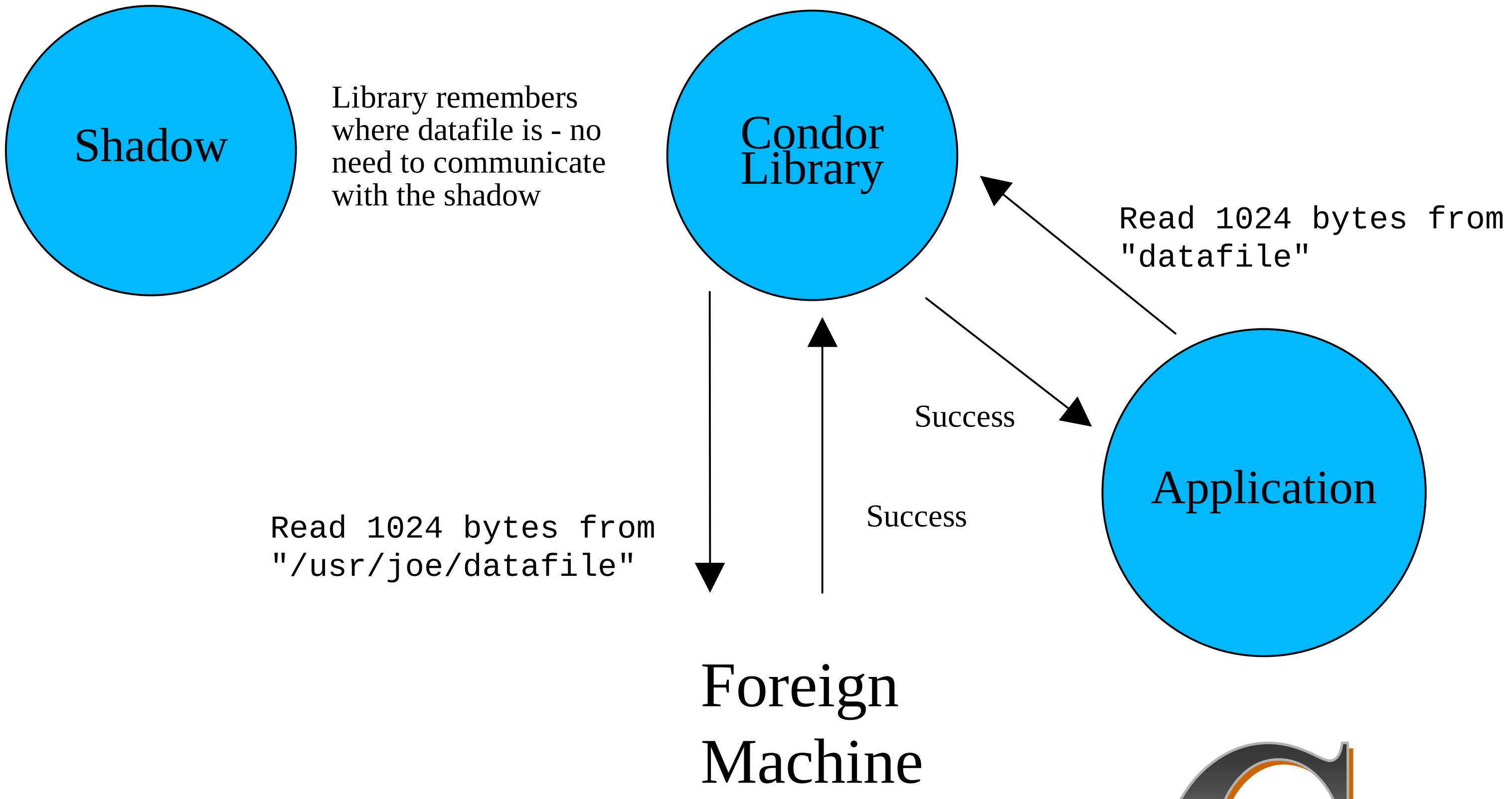
- Buffering:
  - None.
  - Buffer partial data.
  - Stage whole file to local disk.

Reading data from a file



Reading data from a file

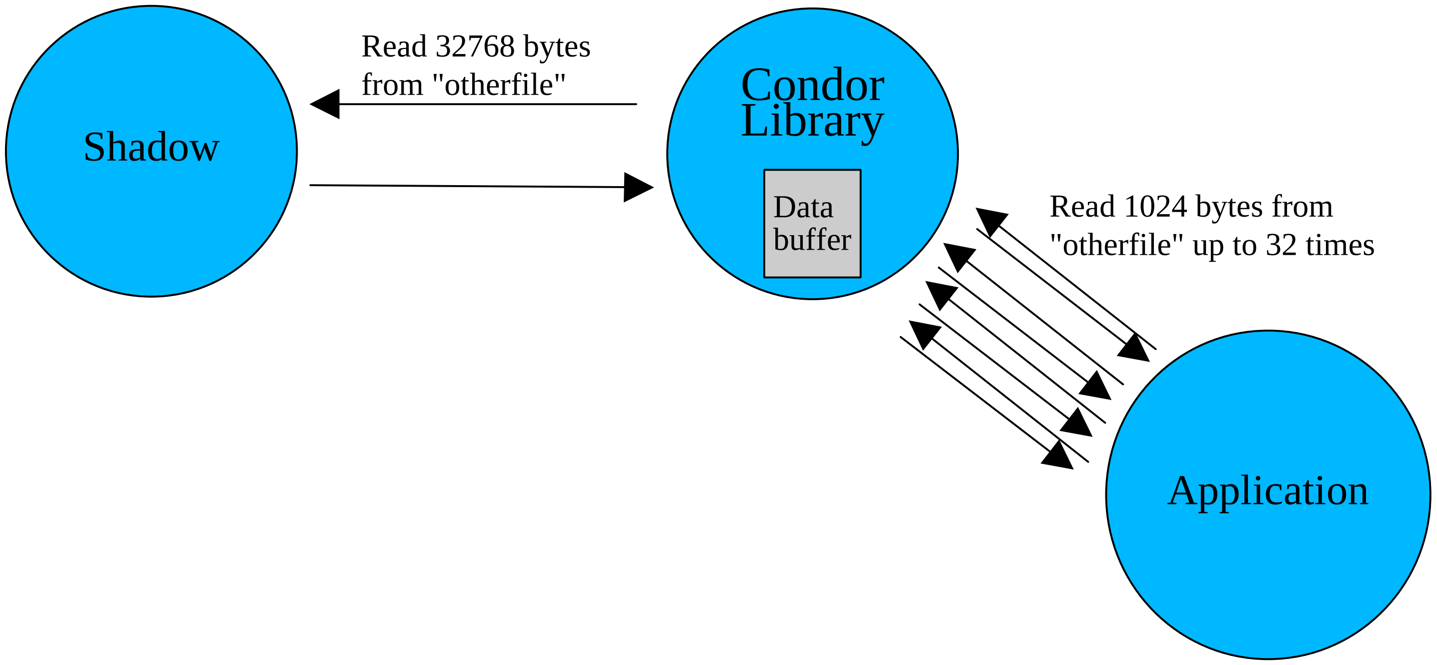
Low latency, random-access data source: Read directly



Shadow
Library remembers where datafile is - no need to communicate with the shadow
Condor Library
Read 1024 bytes from "datafile"
Success
Application
Read 1024 bytes from "/usr/joe/datafile"
Success
Foreign Machine

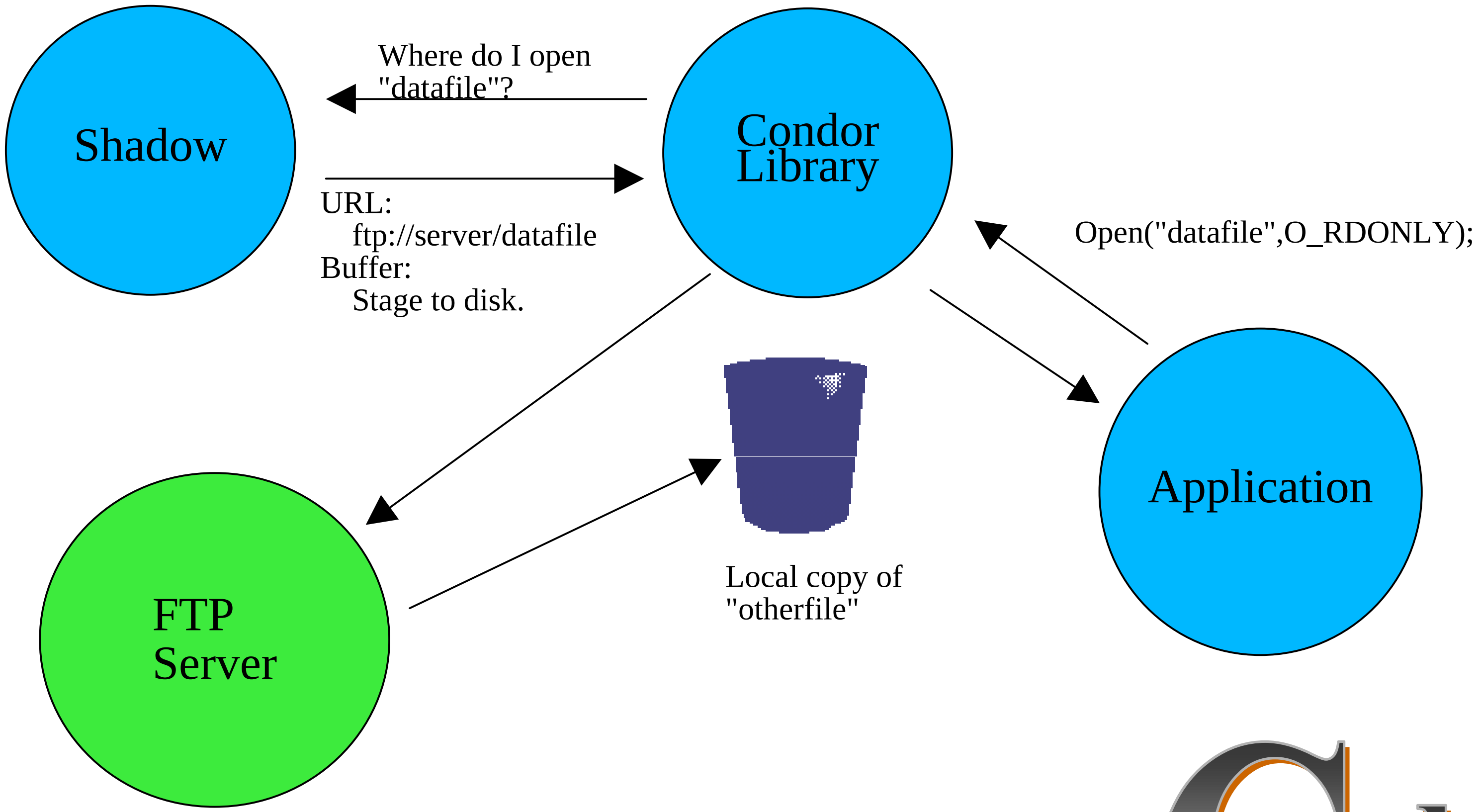
Reading data from a file

High-latency, random-access data source: Buffer large chunks


Shadow
Read 32768 bytes from "otherfile"
Condor Library
Data buffer
Read 1024 bytes from "otherfile" up to 32 times
Application

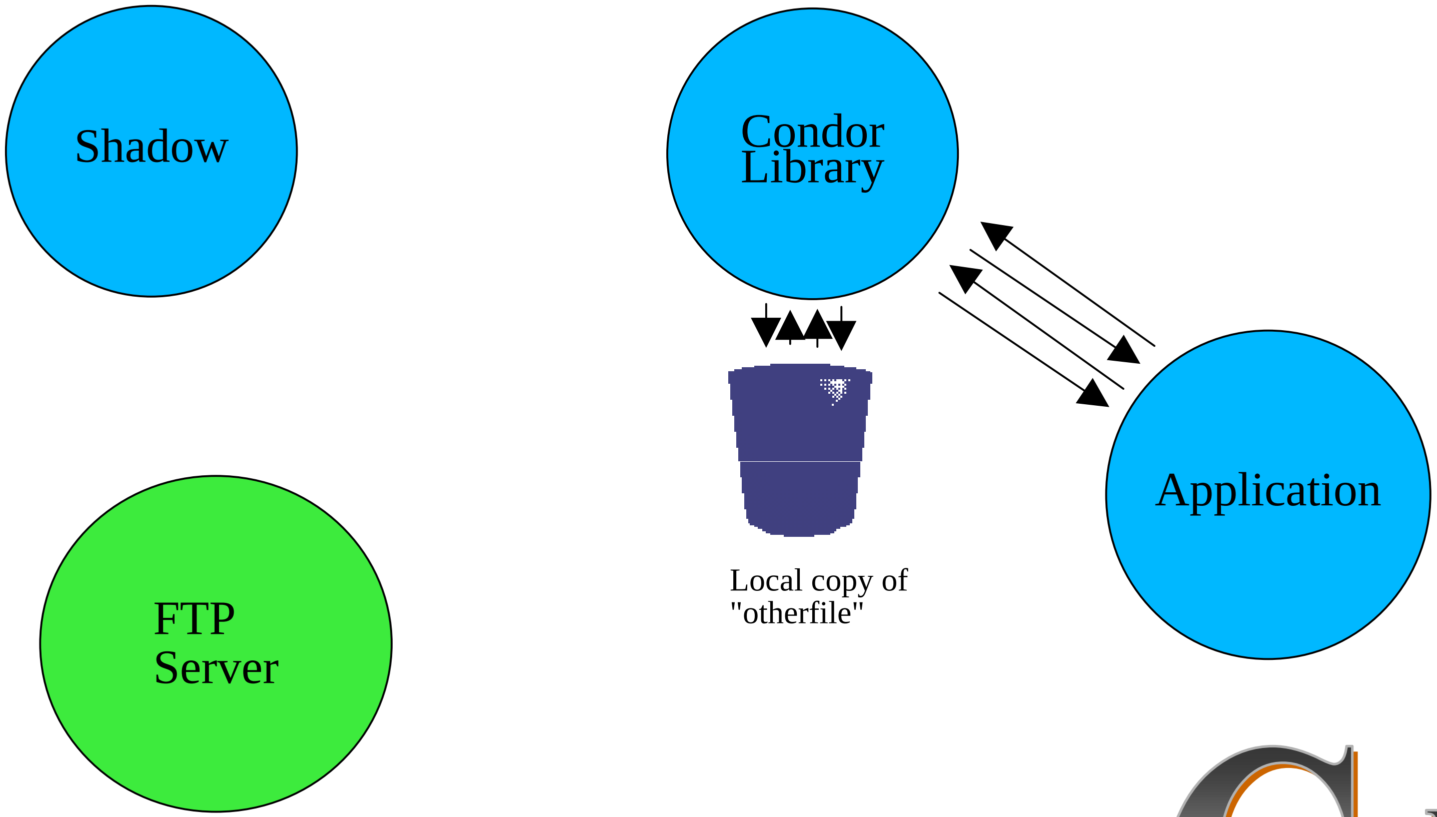
Reading data from a file

High-latency, sequential-access data source: Stage file to local disk.



Reading data from a file

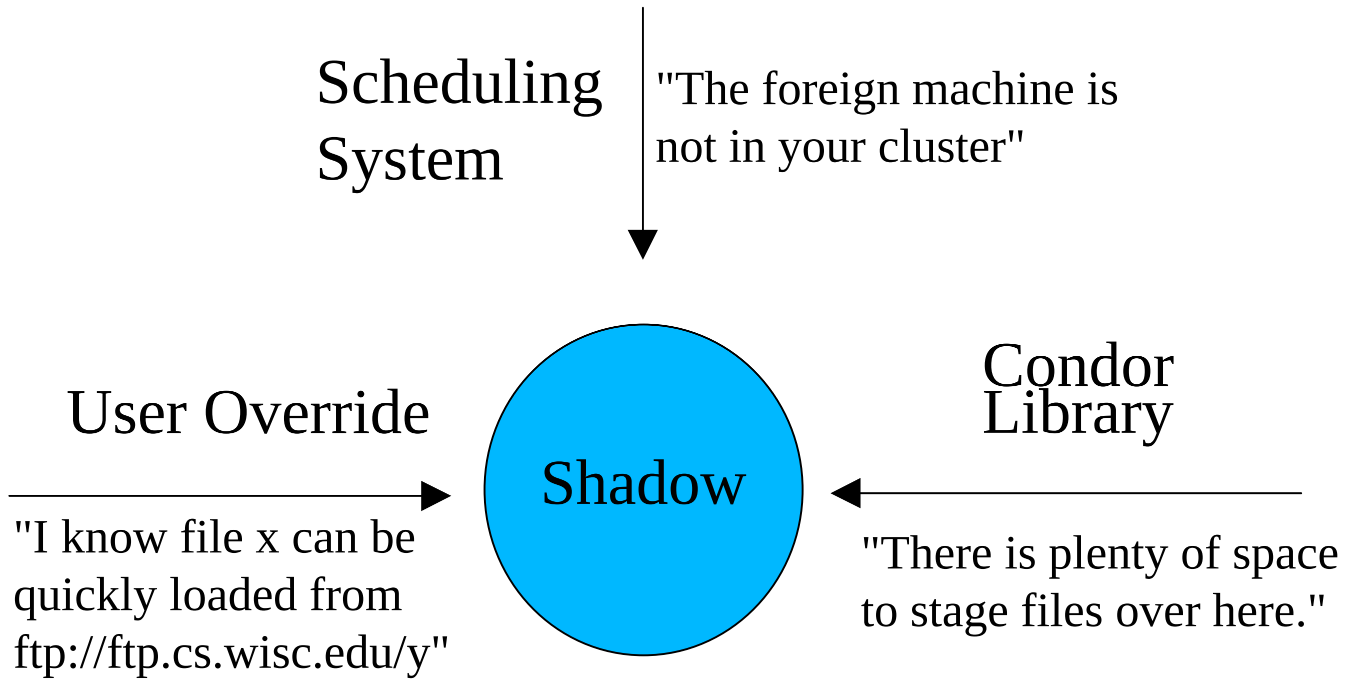
Random access service can be provided from the local copy.



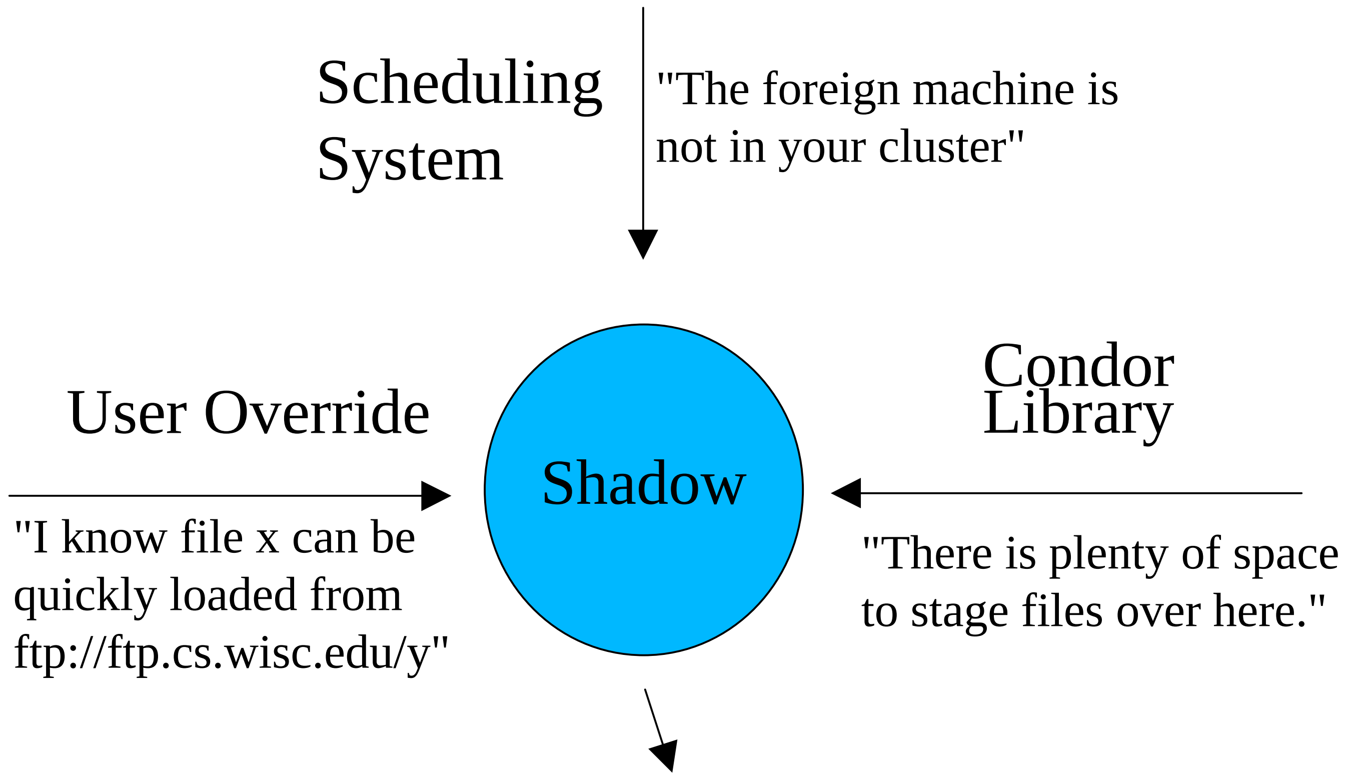
Guiding Principle

- Policy in shadow, mechanisms in library.
  - Shadow makes policy decisions because it knows the system configuration.
  - Library is closest to the application, so it routes system calls to the destination selected by the shadow.

Policy at Shadow


Scheduling System
"The foreign machine is not in your cluster"
User Override
"I know file x can be quickly loaded from ftp://ftp.cs.wisc.edu/y"
Shadow
Condor Library
"There is plenty of space to stage files over here."

Policy at Shadow



"The foreign machine is not in your cluster"

"I know file x can be quickly loaded from ftp://ftp.cs.wisc.edu/y"

"There is plenty of space to stage files over here."

"Direct all requests for x to ftp://ftp.cs.wisc.edu/y"

Policy Decisions

- May be different on each foreign machine
  - In same building: "use foreign machine"
  - In other country: "use home machine"
- May change as job migrates
  - same building -> other country
- May change by user control
  - "Let's see if NFS is faster than AFS"

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Build Your Own: Bypass

- Generalize remote I/O -> split execution.
- Building split execution systems is hard.
- Bypass is a tool for building split execution systems.

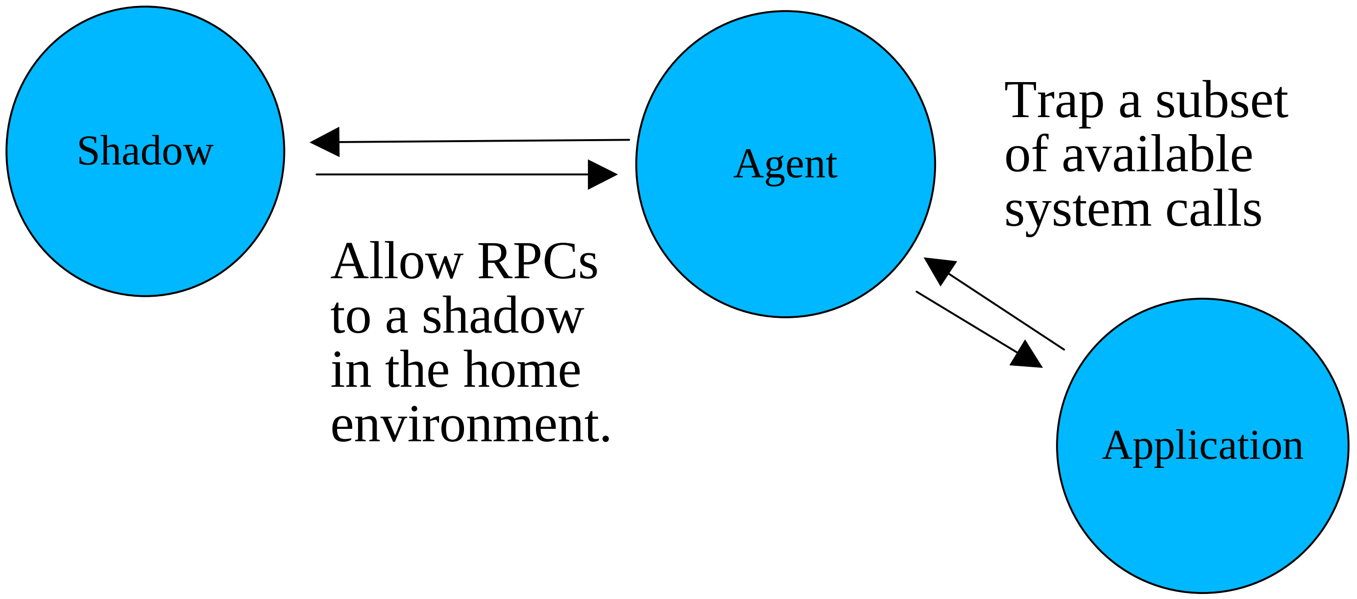
Build Your Own: Bypass (Cont.)

- Unlike Condor, Bypass can be used on any UNIX program without re-linking.
- Example: GASS Agent

Generalized Split Execution

Allow arbitrary code at the home machine.

Replace them with arbitrary code.



Allow RPCs to a shadow in the home environment.

Trap a subset of available system calls

Split Execution is Hard

- Trapping system calls involves a large body of knowledge of particular OS and version
  - Library entry points:
    - _read, __read, __libc_read
  - System call entries:
    - socket(), open("/dev/tcp")
  - Wacky header files:
    - #define stat(a,b) _xstat(VERSION,a,b)

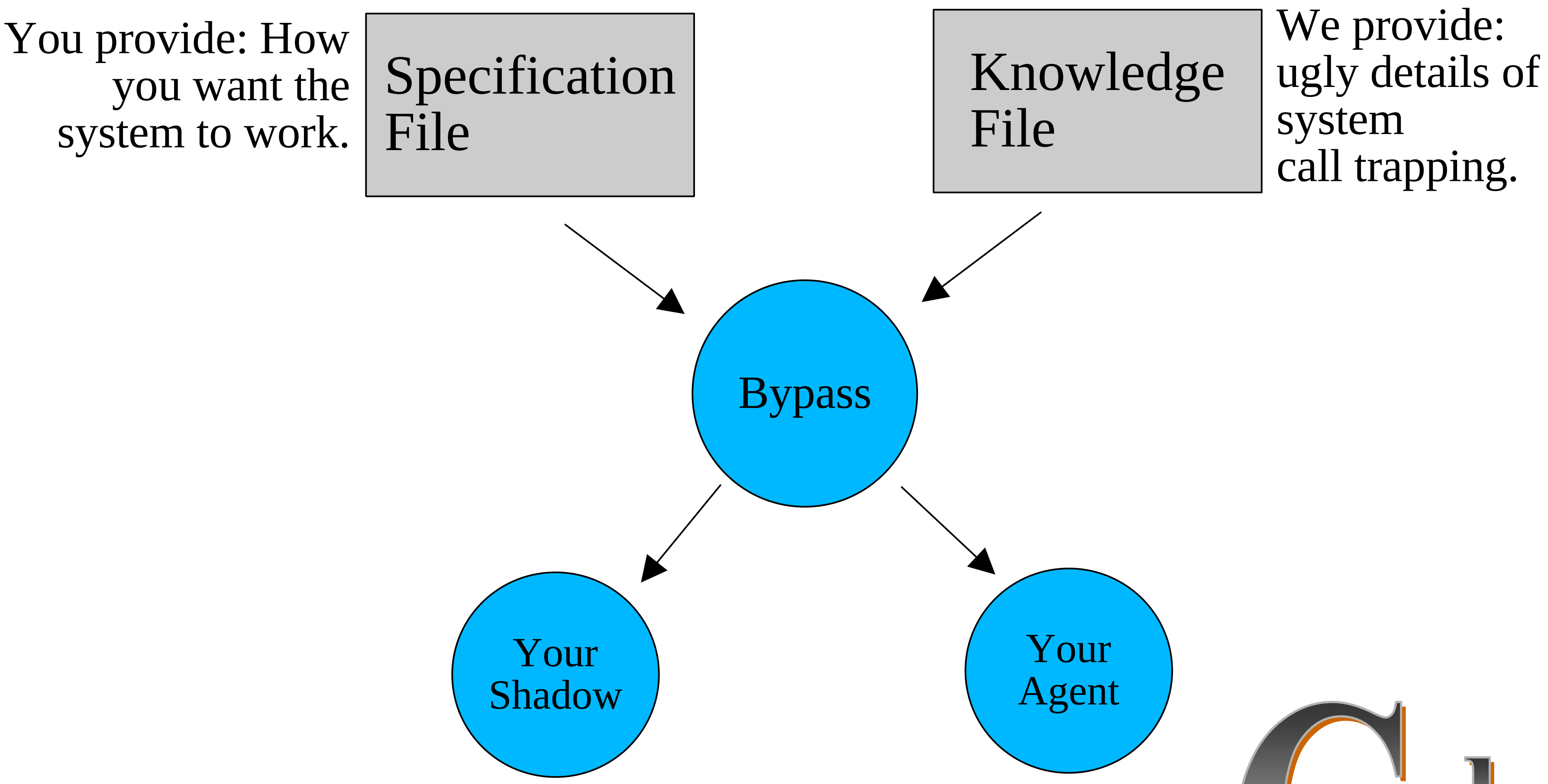
Split Execution is Hard (Cont.)

- RPCs must be platform-neutral
  - Byte sizes and ordering
    - off_t is 8 bytes on Alpha, but 4 bytes on Intel
  - Structure contents and order
    - struct stat has different members on different platforms
  - Symbolic values
    - O_CREAT is a source-level symbol, but its actual value is different on every platform.

Split Execution is Hard (Cont.)

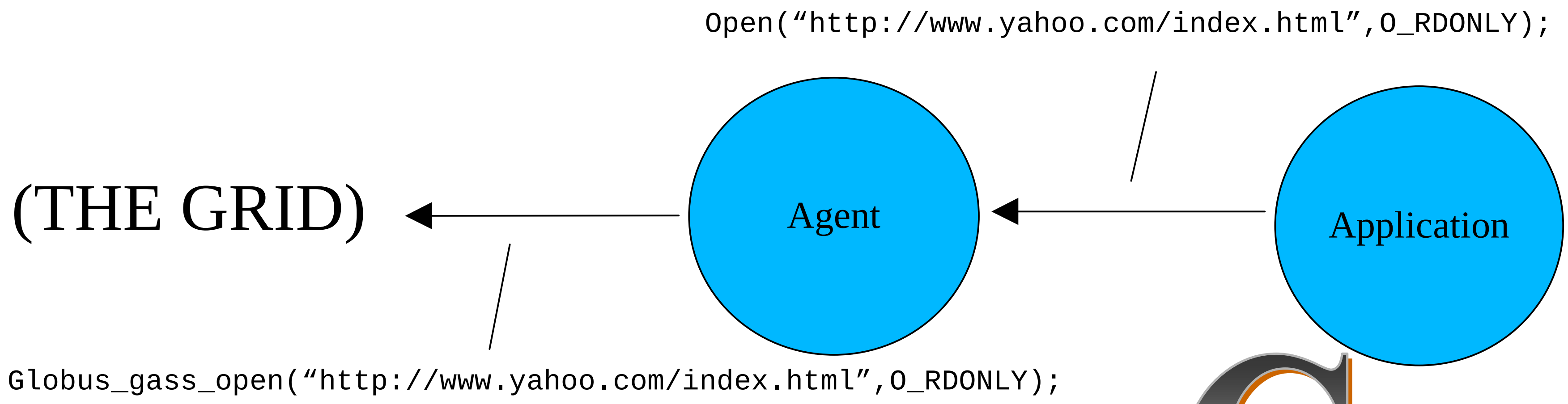
- The code replacing system calls must be able to execute the original system calls!
- Example: Sandboxing
  - Trap open().
  - Check for unauthorized file names.
    - Return failure for some.
    - Re-invoke the original open() for others.

Bypass Makes it Easy!


You provide: How you want the system to work.
Specification File
Knowledge File
We provide: ugly details of system call trapping.
Bypass
Your Shadow
Your Agent

Example: GASS Agent

› Let's create an Agent that changes all calls to UNIX open() and close() into their analogues in Globus GASS. This will instrument the application with remote file fetching and staging.



Open("http://www.yahoo.com/index.html",O_RDONLY);
(THE GRID)
Agent
Application
Globus_gass_open("http://www.yahoo.com/index.html",O_RDONLY);

Example: GASS Agent (Cont.)

```
agent_prologue
{{
      @include "globus_common.h"
      @include "globus_gass_file.h"
}};

int open( const char *name, int flags, [int mode] )
      agent_action
      {{
            globus_module_activate( GLOBUS_GASS_FILE_MODULE );
            return globus_gass_open( namame, flags, mode );
      }};

int close( int fd )
      agent_action
      {{
            return globus_gass_close( fd );
      }};
```

Example: GASS Agent (Cont.)

- Generate the source code.
  - bypass -agent gass.bypass
- Compile into a shared library.
  - g++ gass_agent.C (libraries) -shared -o gass.so
- Insert the library into your environment.
  - setenv LD_PRELOAD /path/to/gass.so

Example: GASS Agent (Cont.)

- Now, run any plain old UNIX program. The program may be given URLs in place of filenames. Globus GASS will stage and cache the needed files.

```
% cp http://www.yahoo.com/index.html /tmp/yahoo.html

% grep address http://www.cs.wisc.edu/index.html

  <LI> <A HREF="/academic.html">Academic information</A>
```

Bypass

- Uses ideas from Condor, but is a separate tool.
- User specifies design, Bypass provides details.

Bypass (Cont.)

- Can be applied to any unmodified, dynamically-linked UNIX program at run time.
  - Works on Linux, Solaris, IRIX, OSF/1.
  - Static linking only on HP-UX.

Bypass (Cont.)

- The "knowledge file" is certainly not complete!
  - Our experience: Each new OS version has new tricks in the standard library that must be foleded into the knowledge file.

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Future Work

- Lots of new plumbing, but still adding faucets
  - FTP, SRB, GASS, SAM …
- Find and use third-party staging grounds?
  - Turn checkpoint server into general staging ground.

Future Work (Cont.)

- Interaction with CPU scheduling:
  - Release CPU while waiting for slow tape?
  - Stage data, then allocate CPU?

In Summary…

- Harnessing large numbers of CPUs requires that you use unfriendly machines.
- Remote I/O is an adapter which provides a friendly execution environment on an unfriendly machine.

In Summary… (Cont.)

- Condor uses remote I/O to homogenize the many machines in a Condor pool.
- Bypass allows the quick construction of split execution systems, allowing remote I/O techniques to be used outside of Condor.

Need More Info?

- Demo of Bypass on Wednesday in Room 3381.
- Contact Douglas Thain (thain@cs.wisc.edu)
- Questions now?