THE PYPY SANDBOX

Using the PyPy Sandbox to Explore Mobile Code Sandboxing

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The PyPy Sandbox (An Introduction)

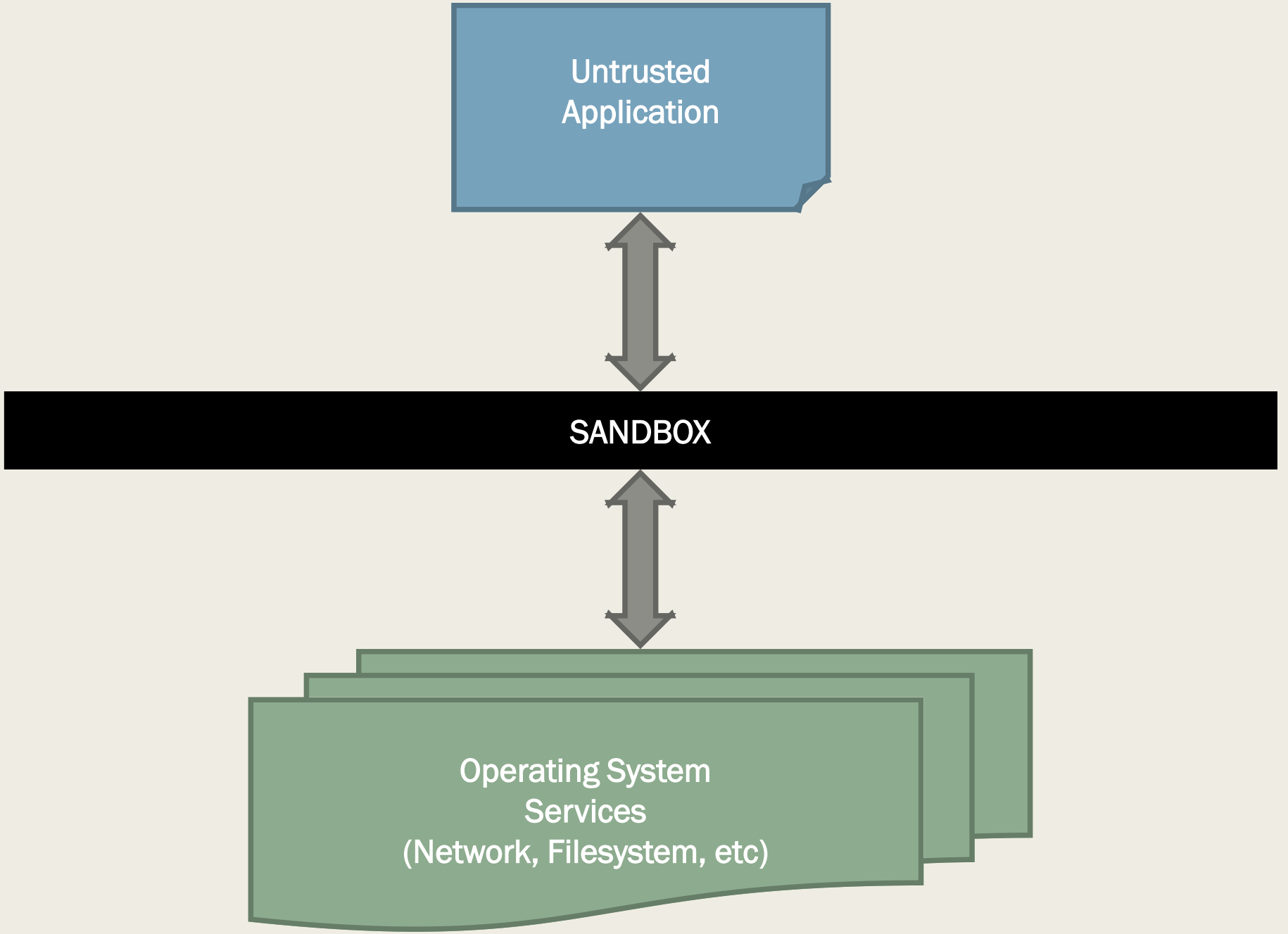
- The PyPy Project
  - *Replacement for Cpython*
  - *Faster execution of most Python code*
  - *Current versions: 2.7.13 and 3.5.3*
- The PyPy Sandbox is a Secondary Feature
  - *Execution of* **untrusted** *Python scripts*

The Problem with Computers

- Computer processors do ***exactly*** what they're told
- They have no ability to decide if they ***should*** do what they're told
- What if they're told to do something ***harmful***?
- A lot of technology goes into figuring out what should be done
  - *Operating System*
  - *Anti-virus*
  - *Device permissions*

A Sandbox:

- The concept of a sandbox is an environment where destruction doesn't matter
- In practice, it is an interceptor between applications and the OS
- The interception layer enables:
  - *Policy Enforcement*
  - *"Sensor" Translations*
  - *"Command" Translations*

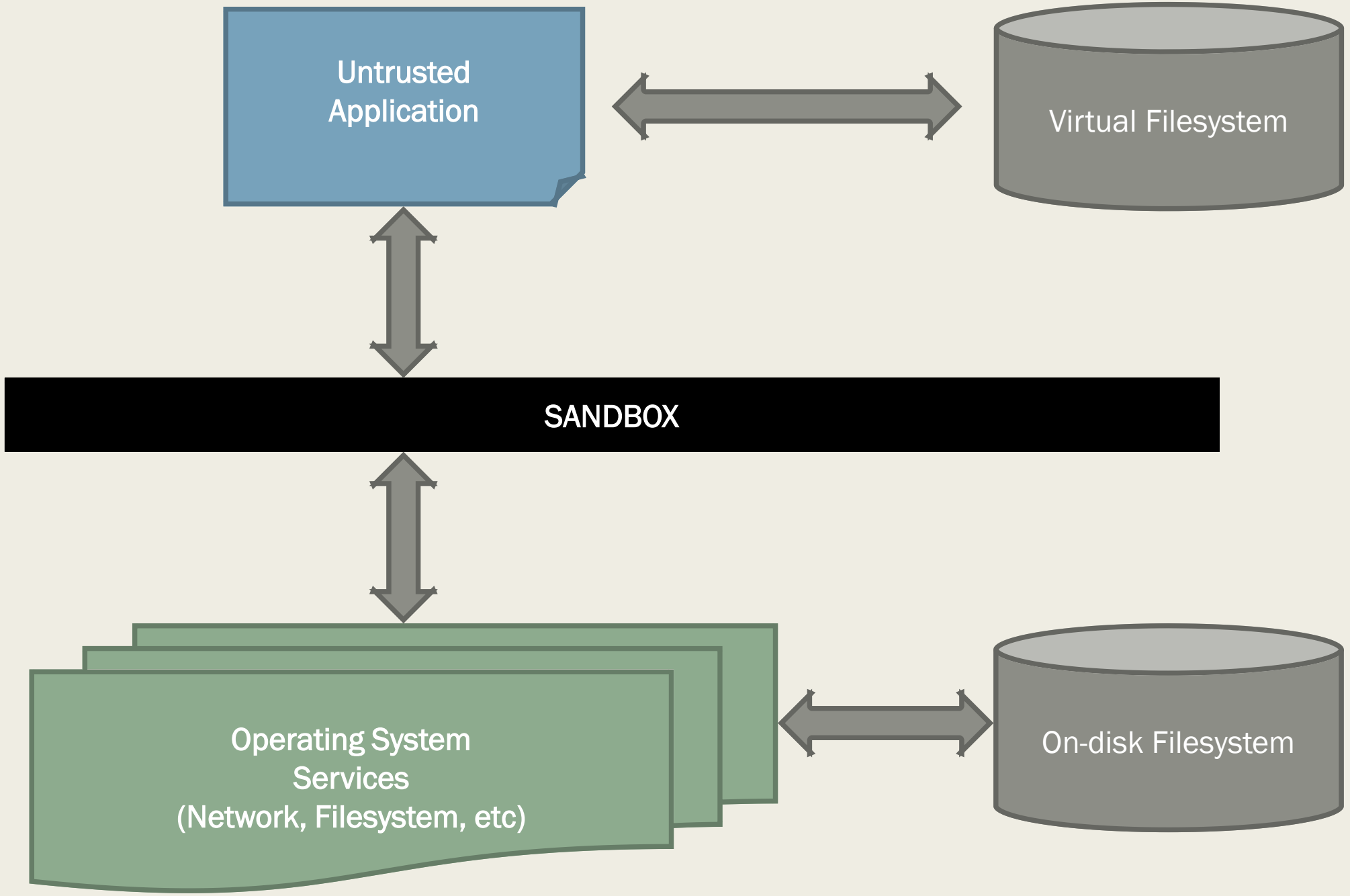

Untrusted
Application
SANDBOX
Operating System
Services
(Network, Filesystem, etc)

Policy Enforcement

- Most common use of a Sandbox
- Each incoming request to the operating system, ***and response***, can be inspected
  - *Requests and responses can be allowed, denied,* **or modified**
  - *Policy based on request/response type, parameters, state of the system, etc*
  - *Examples:*
    - Network Access (Deny, Same-Origin Policy)
    - File Access (Read Only, Write-to-Temp)
    - Even memory allocations

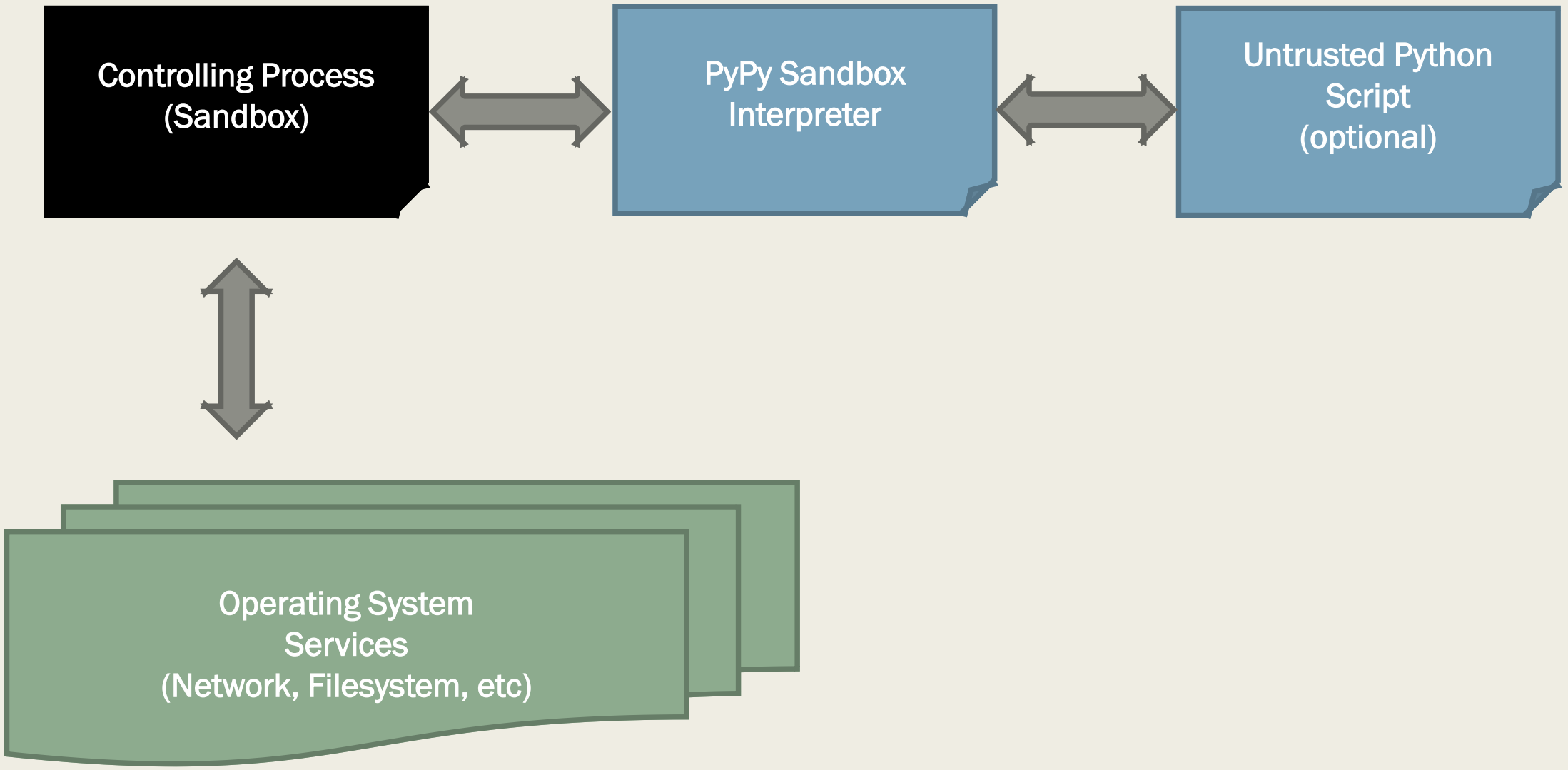
Sensor/Command Translations

- Policy is not just about allow/deny but rewrite/modify
- Any risky call (e.g., syscall) can be rewritten with safer parameter
  - *(Or a risky call could be re-written to a safer call with similar semantics)*
- But a sometimes overlooked Sandbox capability is lightweight virtualization
  - *I like to call this “Sensor” translations*
  - *The Sandbox can control what the application “sees”*
  - *For example, it can present a virtual filesystem*
  - *Or provide alternative API replacements that are more secure*


Untrusted Application
Virtual Filesystem
SANDBOX
Operating System Services (Network, Filesystem, etc)
On-disk Filesystem

The PyPy Sandbox

- Creates a limited PyPy Interpreter
  - *No direct calls to the OS (system calls, etc)*
  - *Does not allow dynamic libraries, including compiled Python modules*
- Instead, a controlling process receives OS calls marshalled over a pipe
  - *This process provides the sandboxing and enforces security policies*
  - *For permitted calls, it performs the call itself and sends back the result*
  - *Or, it can modify the request and/or results*


Controlling Process
(Sandbox)
PyPy Sandbox
Interpreter
Untrusted Python
Script
(optional)
Operating System
Services
(Network, Filesystem, etc)

Infinite Variety of Sandboxes

- Different controlling processes create different kinds of sandboxes
- Controlling process does not have to be Python
- The PyPy project provides a default controlling process called “pypy_interact.py”
  - *Can run a python “shell” or execute a script*
  - *Many OS subsystems completely disabled including network operations*
  - *Read only virtual file system*
    - /bin – virtual bin directory with pypy and a few required directories
    - /tmp – temp directory that potentially maps to a real directory
    - NOTE: the interpreter lives in the sandbox and executes the script from virtual /tmp!

```
x$ mkdir my_sandbox_tmp
x$ echo "this is a test" > my_sandbox_tmp/datafile.txt
x$ ./pypy_interact.py --tmp=my_sandbox_tmp pypy3-c-sandbox
```

```
>>>> import os
>>>> os.listdir('/')
['dev', 'bin', 'tmp']
```

```
>>>> os.listdir('/tmp')
['datafile.txt']
```

```
>>>> f = open('/tmp/datafile.txt')
>>>> f.read()
'this is a test\n'
```

```
>>>> open('/tmp/newfile.txt','w+')
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
FileNotFoundError: [Errno 2] No such file or directory: '/tmp/newfile.txt'
>>>> open('/tmp/datafile.txt','a+')
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
PermissionError: [Errno 1] Operation not permitted: '/tmp/datafile.txt'
```

Running an Untrusted Script

- Contents of “dangerous_script.py”

```
import os
print("Script Current Working Dir: {}".format(os.getcwd()))
print("Contents of root dir: {}".format(os.listdir('/')))
print("Try to delete /tmp dir with a system call.")
os.system('rm -rf /tmp')
```

```
x$ ls my_sandbox_tmp/
dangerous_script.py  datafile.txt

./pypy_interact.py --tmp=my_sandbox_tmp pypy3-c-sandbox /tmp/dangerous_script.py

Script Current Working Dir: /tmp
Contents of root dir: ['bin', 'tmp', 'dev']
Try to delete /tmp dir with a system call.
Traceback (most recent call last):
  File "/tmp/dangerous_script.py", line 5, in <module>
    os.system('rm -rf /tmp')
RuntimeError
```

Sample Sandboxing Functions

```
def do_ll_os__ll_os_write(self, fd, data):
    if fd == 1:
        self._output.write(data.decode())
        self._output.flush()
        return len(data)
    if fd == 2:
        self._error.write(data.decode())
        return len(data)
    raise OSError("trying to write to fd %d" % (fd,))
```

```
def do_ll_os__ll_os_read(self, fd, size):
    f = self.get_file(fd, throw=False)
    if f is None:
        return super().do_ll_os__ll_os_read(fd, size)
    else:
        if not (0 <= size <= (2**64)):
            raise OSError(errno.EINVAL, "invalid read size")
        # don't try to read more than 256KB at once here
        return f.read(min(size, 256*1024))
```

Using PyPy in the Classroom

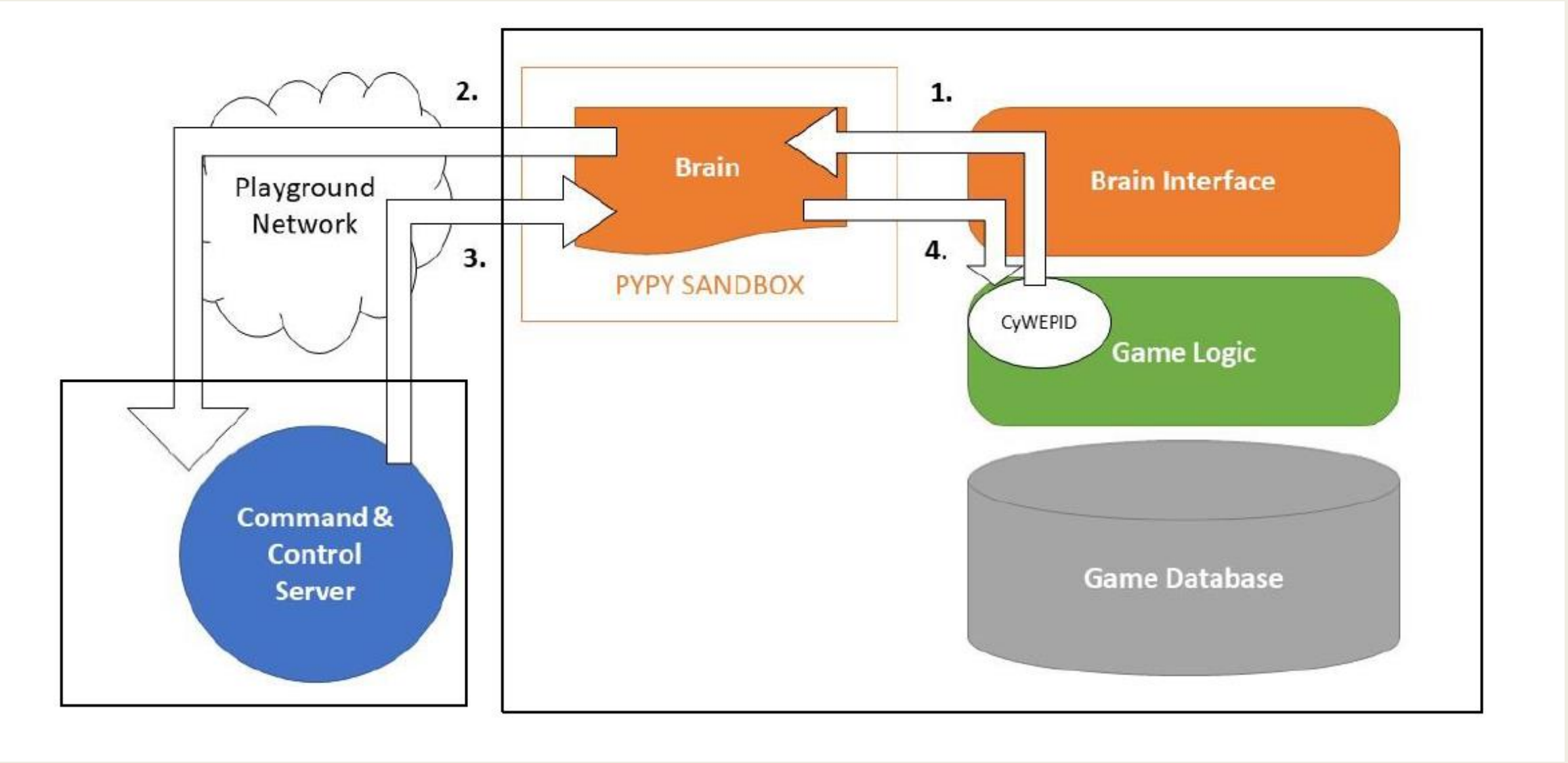
- Network Security at Johns Hopkins University
- Student Labwork:
  - *Uses "Playground," an education overlay network created by the Author*
  - *Students create their own version of TCP within Playground*
  - *Students create their own version of TLS within Playground*
  - *Students build mobile code applications on top of Playground using PyPy*
    - Parallel processing (e.g., Traveling Salesman)
    - Adapt pypy_interact to support new features (writing to filesystem)

Modifying pypy_interact

- Requires students to carefully think about sandbox policies and features
- For example, implementing write
  - *Requires students to understand virtual file system*
  - *Implement policy for when writes are allowed*
    - Specific directories
    - Maximum size
  - *Argument sanitation (e.g., "../../.." doesn't escape the sandbox)*
- Another example: implementing network operations

Developing Bot Brains

- Advanced Network Security
- “CyberWar_EDU” project
  - *Gameboard with semi-autonomous “bots”*
  - *Students can (re-)program the bots with a Python brain script*
  - *Each brain scripts run inside a PyPy sandbox instance*
  - *Each brain needs to connect to*
    - The Game Board (over TCP)
    - The Student’s command and control server (over Playground’s network)


2.
1.
Brain
Brain Interface
Playground
Network
3.
4.
PYPY SANDBOX
CyWEPID
Game Logic
Command &
Control
Server
Game Database

Sandbox “Brain” Extensions

- Extended pypy_interact.py to brain_interact.py
- Virtual file system supports two special virtual files:
  - *“game://” which opens a socket to the gameboard*
  - *“<playground-protocol>://<host>:<port>” which connects to C&C*
- Allows writing within the /tmp directory so students can re-program their brains!

Sample Modified Sandbox Functions

```
def do_ll_os__ll_os_open(self, name, flags, mode):
    if name.startswith(b"game://"):
        host, port = '127.0.0.1', 10013
        try:
            protocol = asyncio_interface.sandbox_connect(host, port)
        except Exception as e:
            print("Exception on game connection: {}".format(e))
            raise RuntimeError("Could not open connection to game because {}".format(str(e)))
        fd = self.allocate_fd(protocol, ProtocolSocketWrapper())
        self.sockets[fd] = True
        return fd
```

The “Null” Brain

```
import time
import os

def brainLoop():
    gameSocket = open("game://", "rb+")
    ccSocket = open("default://20181.0.1.1:5000","rb+")

    while True:
        gameData = os.read(gameSocket.fileno(), 1024)
        ccData = os.read(ccSocket.fileno(), 1024)

        if gameData: os.write(ccSocket.fileno(), gameData)
        if ccData: os.write(gameSocket.fileno(), ccData)

        if not gameData and not ccData:
            time.sleep(.5) # sleep half a second every time there's no data

if __name__=="__main__":
    try:
        brainLoop()
    except Exception as e:
        print("Brain failed because {}".format(e))
```

Eventual Goal for Lab Work

- Students reprogram bots over the network
- Students attempt to reprogram other student bots to take them over
- Eventually, want a student sandbox within the bot sandbox
  - *Bot sandbox is to protect the game from student malicious code*
  - *Student sandbox is to protect bot against false reprogramming*
  - *Give students a chance to create “firmware” that detects bad “software”*

Quick Review

- PyPy sandbox
  - *Provides lightweight Python sandboxing*
  - *A modified interpreter has no system calls*
  - *Dangerous calls are processed by a controlling process*
  - *Policy enforces allow, deny, and modify*
  - *Modify can be used to create a virtual system*
- Students can experiment extensively and gain insight into mobile code execution

Final Notes

- PyPy sandbox is a prototype. It is not ready for production code
- The current PyPy sandbox is somewhat broken for 2.7, inoperable for 3.5
- For my class, I fixed 3.5. I plan to submit my changes to PyPy shortly
- I have discussed providing on-going maintenance with the PyPy team

Thank You!

- Feel free to ask questions!
- Links:
  - *The PyPy project:* http://pypy.org
  - *Playground code:* https://github.com/CrimsonVista/Playground3
  - *CyberWar EDU code:* https://github.com/CrimsonVista/cybersecurity-war
  - *Playground paper:* https://eric.ed.gov/?id=EJ1132824
  - *JHUISI:* https://isi.jhu.edu/