Riverbed

“Enforcing User-defined Privacy Constraints in Distributed Web Services”

Hypothetical Scenario

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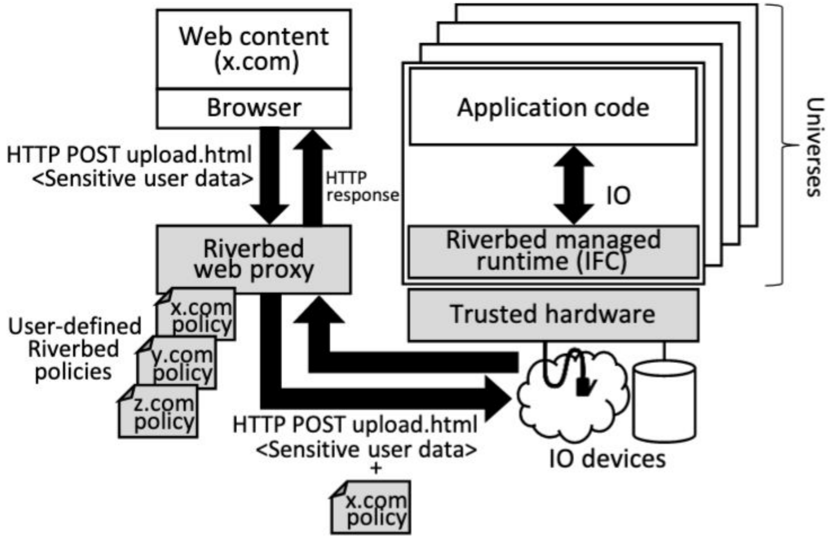
- Slack announces that they send the contents of your chat messages directly to advertising companies (say, doubleclick)
- For people that want to opt out they provide a setting to do so
- You check the box to opt out
- But how do you know that Slack does what you want them to do?
    - Does opting out also cover Slack sending analyses of your data (ie. statistics about your messages) to third party companies?
- In general, how do we trust that Slack isn’t doing anything shady?

Enter Riverbed

Riverbed

- Distributed IFC system that allows *the user to specify the policies* that a *server will abide by* when handling/processing that user's data
- Consists of:
  - (1) A client-side web proxy
  - (2) A modified server-side runtime (PyRB, which is a modified PyPy)
  - (3) Trusted hardware (TPM)
  - (4) A server-side daemon for RB connections

Overview of Riverbed


Web content (x.com)
Browser
HTTP POST upload.html <Sensitive user data>
HTTP response
Riverbed web proxy
User-defined Riverbed policies
x.com policy
y.com policy
z.com policy
HTTP POST upload.html <Sensitive user data> + x.com policy
Application code
IO
Riverbed managed runtime (IFC)
Trusted hardware
IO devices
Universes

How it works

The user can specify in their policy:

- The environment that their data will be processed in
- Whether or not their data can be written to disk
- To which web hosts the data could be passed to

1. The client's RB web proxy initiates an <u>attestation challenge</u> to the server
2. The proxy then sends the user's <u>data</u> along with their <u>policy</u> to the server
3. The RB runtime on the server then uses <u>taint tracking</u> to ensure that the application code respects the user's policies (no unauthorized leaks to disk or network)

Details - User Policies

Example User Policy

```
USER-ID: ALICE
AGGREGATION: False
PERSISTENT-STORAGE: True
ALLOW-TO-NETWORK: x.com
ALLOW-TO-NETWORK: y.com
TRUSTED-SERVER-STACK: {
   83145c082bbf608989f05e85c3c211f83,
   c8cd7ac93cab2b94f65a5b2de5709767f,
        ...
   590f01d8d18b1141988ee1975b3ce3b30
}
```

Details - Attestation

Attestation - Some Jargon

- Jargon
  - *Verifier* = Client
  - *Attestor* = Server

Attestation - Setup

- Requires trusted hardware
  - **TPM - Trusted Platform Module**: A cryptoprocessor with tamper-resistant, non-volitatile RAM and a pub/priv key pair burned into hardware
    - The private key lives only in the chip (ie. never gets released to the rest of the hardware)
    - Upon boot, initializes and then one-by-one extends ("adds to") a cumulative hash using the hashes of the first the BIOS, then the Bootloader, then Kernel Image, Kernel Modules, Software and so on, all within the TPM's memory
      - Exact formula given in paper is given as
        - $reg_{TPM} = SHA1(reg_{TPM} \,||\, \mathbf{value})$
      - Where ***value*** is the SHA1 hash of whatever layer we're verifying
- Attestor machine also has a certificate signed by the TPM manufacturer that binds the attestor to its public key
  - TPM manufacturer ~= HTTPS Certificate Authority

Attestation - Process

- The client [*verifier*] downloads the certificate of the TPM manufacturer
- Client generates nonce and sends to server [*attestor*]
- Server has its TPM chip generate a signature over the nonce and the cumulative hash of the software stack via the TPM's private key (the signature is called a *“**quote**”*)
- Server sends back:
  - (1) Server's attestor cert
  - (2) The quote (cumulative signature)
  - (3) Cumulative hash
  - (4) List of SHA1 hashes for each of the software components on the stack
- Then client then verifies the quote, cumulative hash, then the list of the software components
- If all checks out, then it's good! (all the software is what's expected)
- If not, then reject

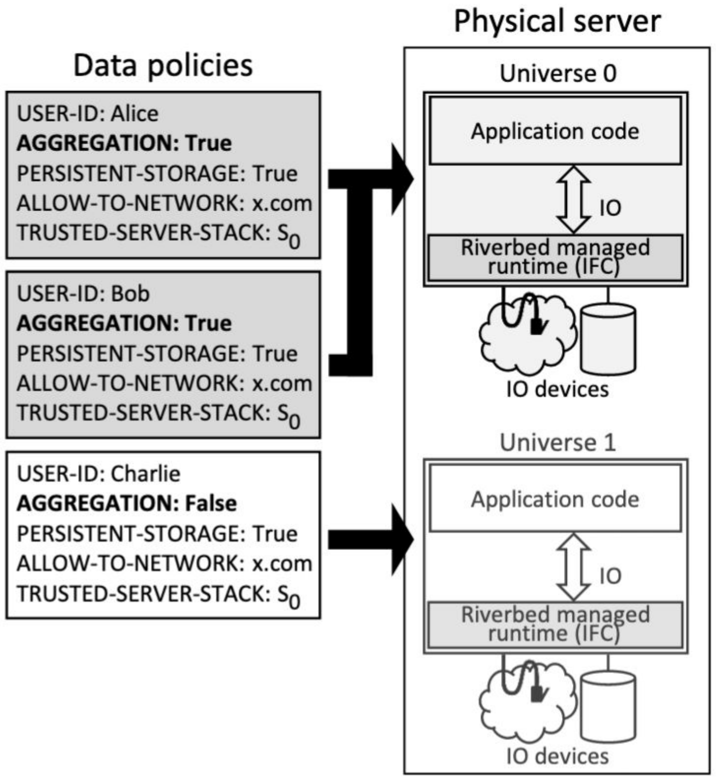
Issues? Merits?

Details: Universes

RB Universes

- *Universe* = Copy of a server-side service
- Users with the same/compatible policies get to run on the same copy of a service
- Users with incompatible policies get run in different universes
- Users with *AGGREGATION = False* get run in their own universes

Example Policy Interaction



Issues? Merits?

Details - Threat Model

Who’s trusted?

Threat Model

- Weakly Adversarial
    - *Honest mistakes, but not dishonest developers*
- Datacenter operators are trusted
- Entire client side is trusted
    - Except for web content
- HTTPS system is trusted
- (TPM hardware/manufacturer is trusted)

Riverbed + Slack

How would we incorporate Riverbed into the Slack system?

Riverbed + {FB, Twitter, News sites, et. al}

How suitable is Riverbed for other sorts of systems?

Performance

Test Apps

- MiniTwit
  - Mini Twitter App
    - Core features: posting messages, following users
  - Flask + SQLite
  - Policy: Agg, Store = Yes; Data only to researchers’ MiniTwit deployment
- Ionic Backup
  - Mini Dropbox clone
    - Upload+Download+List+Delete files
  - Policy: Store = Yes; User data can’t be sent to other servers
- Thrifty P2P
  - Peer-to-Peer distributed hash table
    - PUT(key, val), GET(key, val)
  - Policy: Agg, Store = Yes; Data could only be written to researchers’ Thrifty Servers

Benchmark	Overhead
Django	1.14x
Render HTML table	1.16x
Code run in PyPy interpreter	1.08x
JSON parsing	1.13x
Python git operations	1.01x
SQL Alchemy	1.05x
Spitfire	1.19x
Twisted	1.17x
Fractal Generation	1.18x
Spectral Norm	1.10x
Raytracing	1.19x

Figure 6: PyRB's performance on representative benchmarks from the Performance benchmark suite [52]. PyRB's performance is normalized with respect to that of regular PyPy. No data was tainted in these experiments.

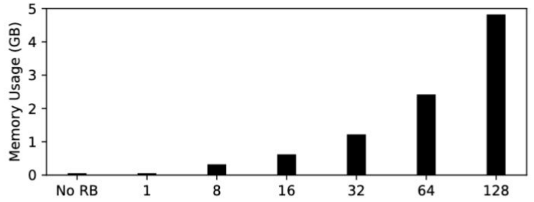


Figure 7: Physical memory pressure in MiniTwit when run without Riverbed, or with Riverbed using various numbers of universes. Note that in MiniTwit, each universe requires only one container. In each test configuration, we measured memory pressure after submitting 1000 requests to each MiniTwit instance that existed in the configuration.

Operation	Without Riverbed	With Riverbed
MiniTwit view timeline	229 ms	252 ms
Ionic download	82.5 ms	83.1 ms
Ionic ls	14.1 ms	14.2 ms
Thrifty GET request	27.5 ms	28.0 ms

Figure 4: End-to-end response times for processing various user requests. For MiniTwit, the user viewed her timeline. For Ionic, the user downloaded a 300 KB file, or asked for a list of the contents of a server-side directory. For Thrifty, the client fetched a 20 byte value from a DHT that contained 2 nodes; the DHT was intentionally kept small to emphasize the computational overheads of Riverbed. The client/server network latency was 14 ms. Each result is the average of 50 trials.

Operation	Regular PyPy	PyRB (no taint)	PyRB (taint)
MiniTwit post message	14 ms	15 ms	15 ms
MiniTwit view timeline	4.1 ms	4.2 ms	4.2 ms
MiniTwit follow user	13 ms	15 ms	15 ms
Ionic upload	2.3 ms	2.5 ms	2.5 ms
Ionic download	4.8 ms	5.0 ms	5.0 ms
Ionic ls	0.43 ms	0.50 ms	0.50 ms
Thrifty PUT request	0.16 ms	0.17 ms	0.19 ms
Thrifty GET request	0.19 ms	0.24 ms	0.24 ms

Figure 5: Server-side overheads for processing various user requests. The workloads are a superset of the ones in Figure 4. Each result is the average of 50 trials.

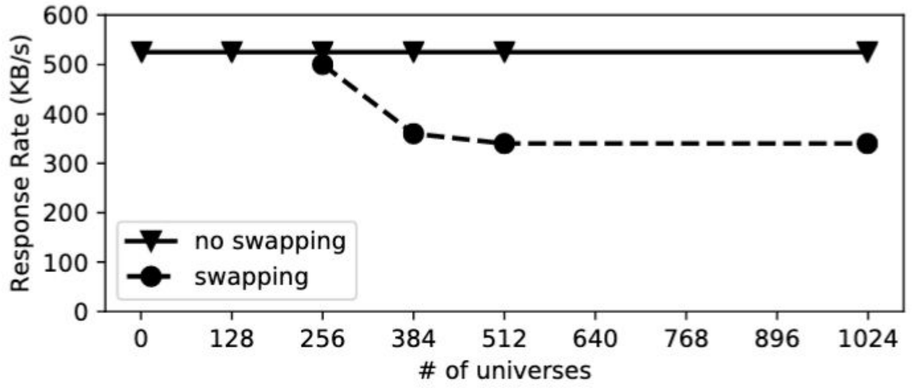


Figure 8: MiniTwit server response rate as a function of (1) the number of universes, and (2) whether the server had 60 GB of RAM or 16 GB of RAM. We used the Apache Benchmark tool [1] to simulate clients that requested MiniTwit timelines which had 100 messages. In each trial, we submitted 1000 requests, with 100 outstanding requests at any given time. For the server with 16 GB of RAM, swapping began with 256 universes.