Reliable User Space TLS tracing with eBPF

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Dom Del Nano

Pixie: eBPF-based Observability for K8s

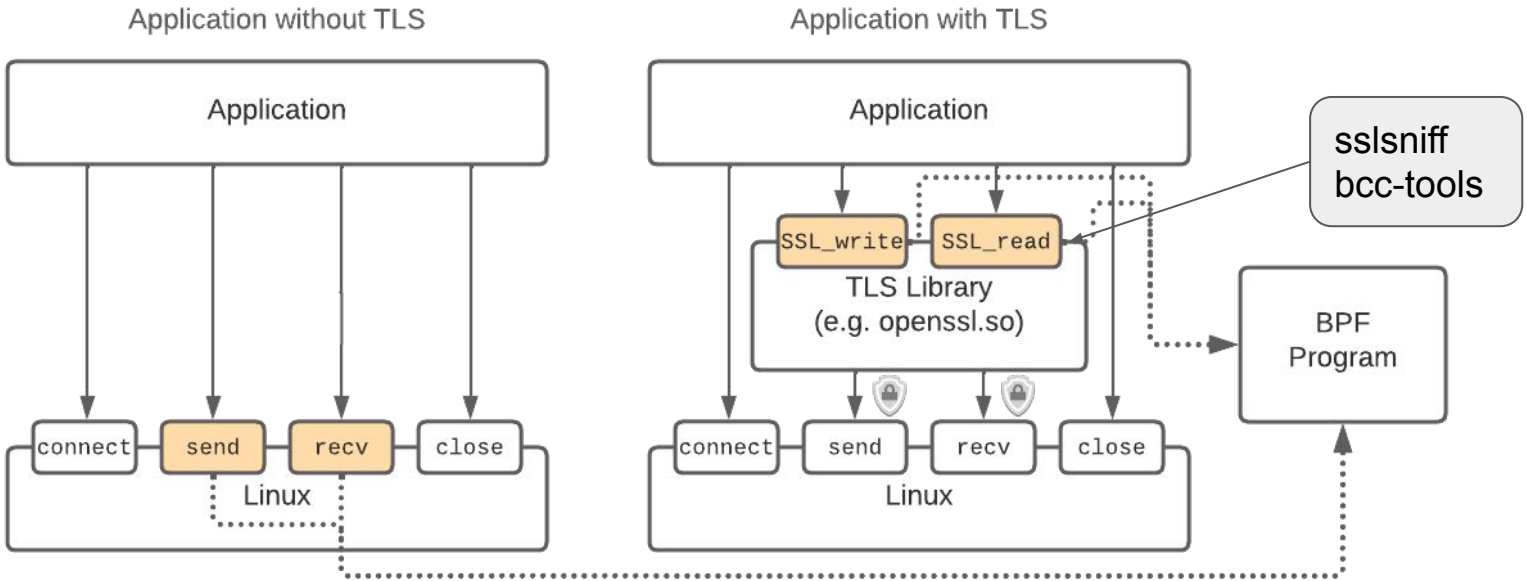
- Observability tool that provides full fidelity protocol traces between your microservices through auto instrumentation.
- Supports many popular protocols (grpc, HTTP, mysql, etc) and can trace TLS encrypted connections.
- TLS is widely adopted in today's environments. Being unable to trace these connections creates substantial blind spots

Roadmap

- Overview of TLS tracing and why handling User space is unavoidable
- Deep dive on Pixie's initial form of TLS tracing and its challenges
- Discuss the latest tracing and how it handles the complex challenges more elegantly
- Future work

TLS Tracing Introduction

- Encryption often occurs within a user space library (OpenSSL, BoringSSL)
- Tracing user space is unavoidable for tracing TLS

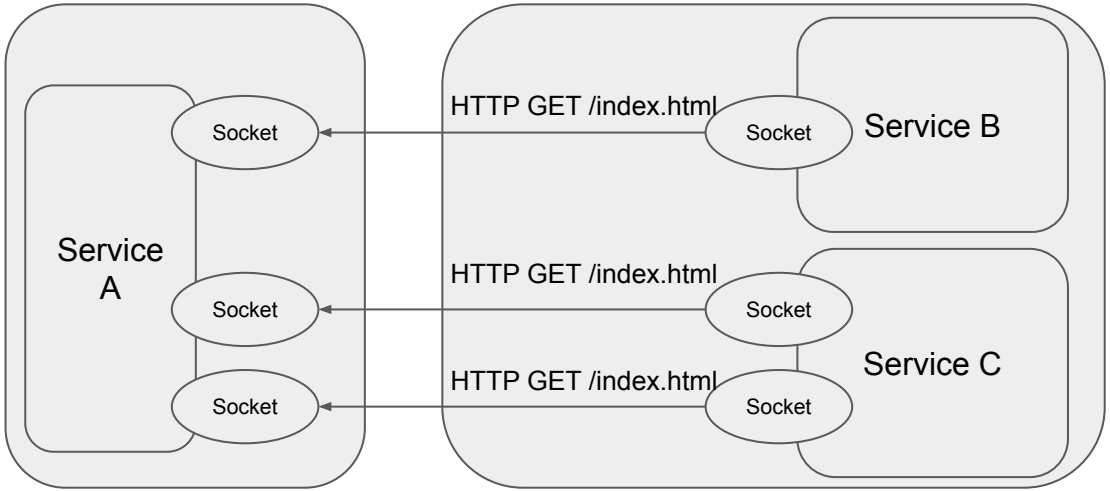


TLS Tracing Production Use Cases

- In reality, tracing production systems comes with more challenges:
  - Different types of linking (dynamic, static)
  - Many popular libraries (OpenSSL, BoringSSL, LibreSSL, GnuTLS, etc)
  - Different ways a given library can be interfaced with
- These use cases require more than the plaintext data
  - Environments today have many microservices and their tracing data must contain additional metadata to make it useful.

Challenges Tracing Encrypted Messages

- Accessing the protocol data is just part of the story
  - The network traffic must be attributed to a particular connection to make the data usable.
  - The connection must be identified so the socket file descriptor must be accessible



Challenges Tracing Encrypted Messages

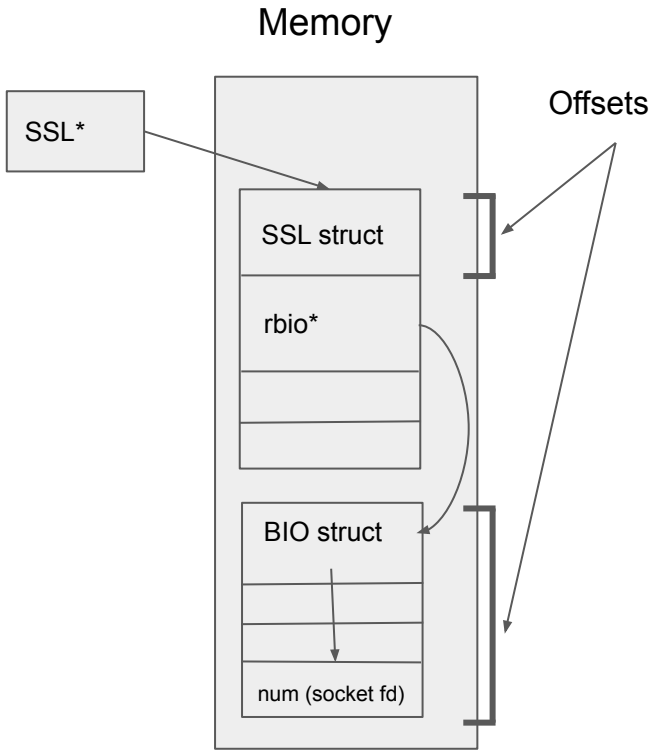
- Plaintext protocol tracing has easy socket fd access from syscall parameters
- Socket file descriptor is not part of the OpenSSL API and must be accessed through another mechanism

```
ssize_t send(int sockfd, const void buf, size_t len, int flags);
```

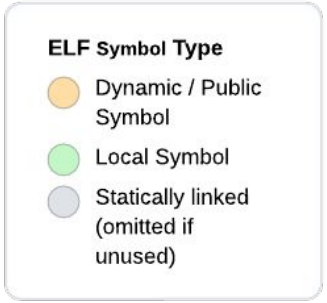
```
int SSL_write(SSL *ssl, const void *plaintext, int num);
typedef struct ssl_st SSL;
typedef struct bio_st BIO;

struct ssl_st {
    BIO *rbio;
    BIO *wbio;
    [ … ]
}
struct bio_st {
    int num;            <-----   Stores the socket file descriptor
}
```

Challenges Tracing Encrypted Messages

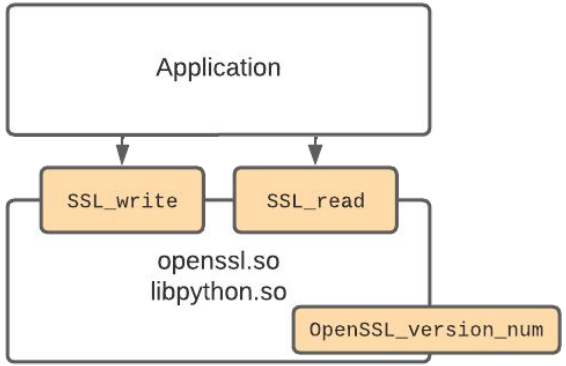
- Initial tracing used memory offsets to access the socket fd
  - Assume stable offsets for a given OpenSSL version.
- This created another challenge – reliably detecting the OpenSSL version.
- Version detection initially relied on *OpenSSL_version_num* function but became more challenging as more libraries and linking options were in scope



OpenSSL Version Detection

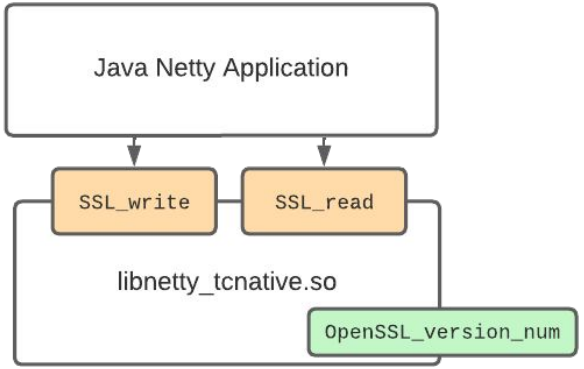


OpenSSL, Python



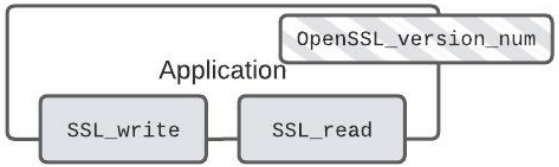
✅dlsym(handle, "OpenSSL_version_num")

Netty-tcnative (BoringSSL variant)



❌dlsym(handle, "OpenSSL_version_num")
✅RawSymbolToFptr<T>(“OpenSSL_version_num”)

Statically linked OpenSSL / BoringSSL

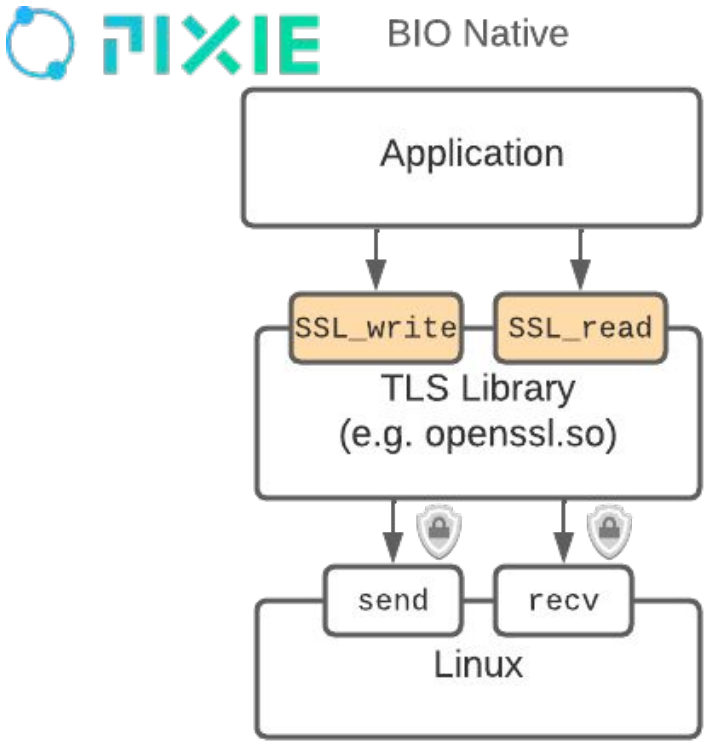


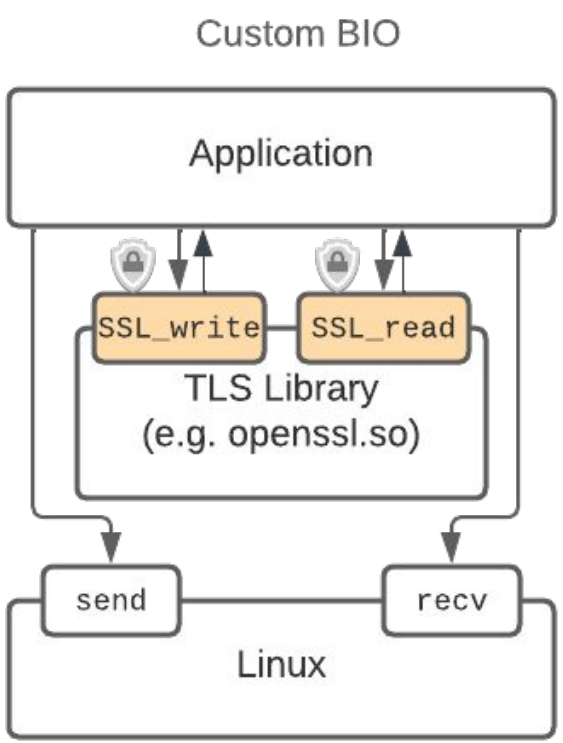
❌dlsym(handle, "OpenSSL_version_num")
❌RawSymbolToFptr<T>(“OpenSSL_version_num”)

Redesigned TLS Tracing

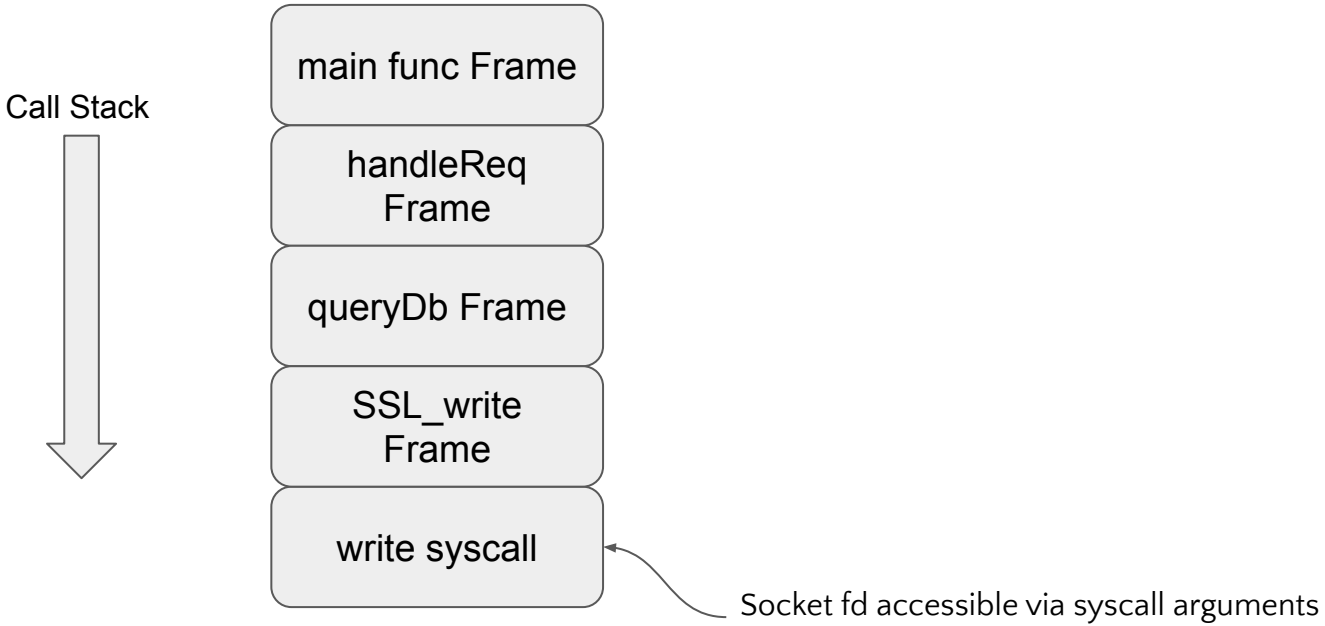
- Standardizing socket fd access appeared too challenging once BoringSSL (static linking) was considered
- Was this the right problem to solve? Relying on user space offsets with no stability guarantees caused more difficult challenges.
- OpenSSL and compatible libraries can be classified in the following ways:
  - BIO Native
    - OpenSSL manages the IO to the underlying socket. Socket is expected to be populated on SSL struct
    - Examples: Nginx, Python
  - Custom BIO
    - OpenSSL is used for encryption exclusively. Application handles IO itself and usually done async (with an event loop)
    - Examples: NodeJS, Envoy

BIO Native vs Custom BIO





BIO Native Deep Dive

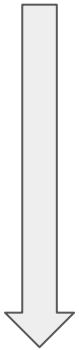


BIO Native vs Custom BIO

BIO Native

Custom BIO

Call Stack



main func Frame

handleReq Frame

queryDb Frame

SSL_write Frame

write syscall

Socket fd accessible via syscall arguments

main func Frame

handleReq Frame

queryDb Frame

SSL_write Frame

Updates in memory buffer

write syscall

Occurs later via async IO / event loop

Redesigned TLS Tracing

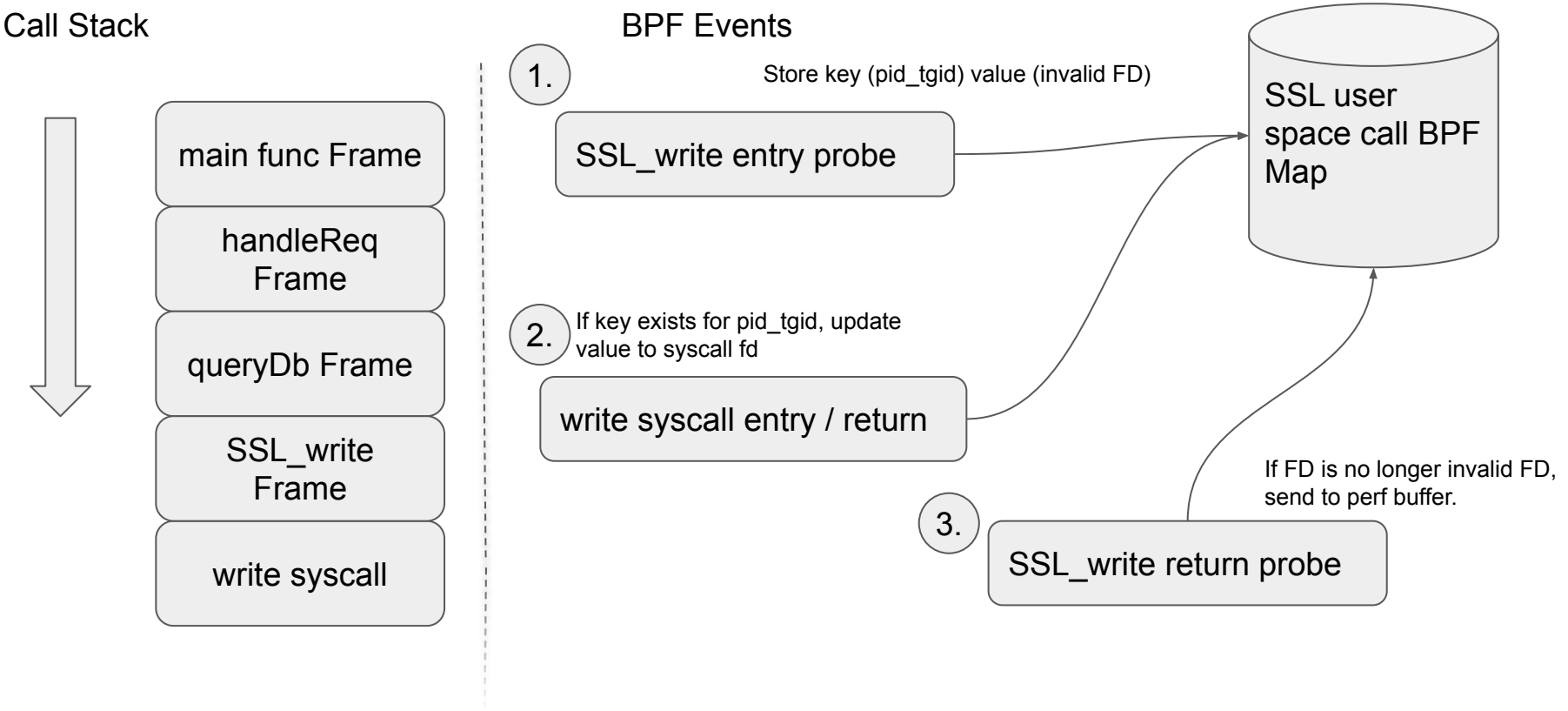
- For BIO native applications, assume that socket syscalls will occur while SSL_write/SSL_read are on the stack*
- This provides an opportunity to pass the socket fd from the nested syscall to user space on the uretprobe.
    - This would have the potential to remove all reliance on user space offsets and would avoid the ongoing maintenance of the existing tracing.

* OpenSSL does have the ability to perform async operations via custom engines. This allows for hardware offload (Intel QAT) and other advanced features.

Validating call stack assumptions

- This implementation relies on the assumptions about the call stack
- Primary concern was if unrelated io / syscalls (different connections) occurred while the TLS library calls are on the stack
- Developed integrity checking into the TLS tracing implementation
  - If more than one syscall occurs between TLS library calls, the fd must be the same throughout – (i.e. buffered writes)
- This integrity check has identified 5 programs that violate this assumption
  - 99.3% of clusters do not see this condition. Half of which belong to the same end users.
  - 99.9376% of total integrity checks are successful

Redesigned TLS Tracing



TLS Tracing Coverage Review

Application	Library	Linking	Library Interface	Initial Impl.	Traced w/ App. Specific Impl.
Nginx	OpenSSL v1.1.0	Dynamic	BIO Native	✅	N/A
Nginx	OpenSSL v1.1.1	Dynamic	BIO Native	✅	N/A
Nginx	OpenSSL v3.x	Dynamic	BIO Native	🚧	N/A
Python <= 3.9	OpenSSL v1.1.x	Dynamic	BIO Native	✅	N/A
Python >= 3.10	OpenSSL v3.x	Dynamic	BIO Native	🚧	N/A

Future Work

- Better support Custom BIO use cases
  - Investigate remove implementation specific tracing.
  - Ideally this would provide broad coverage with supporting additional applications (Envoy, Istio, etc).
- Handle statically linked cases where symbols are completely stripped.

Thank You