CosmOpen: Dynamic reverse engineering on a budget

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Let us inquire diligently

The best and safest method of philosophizing seems to be, first to ***inquire diligently into the properties of things****, and to establish those properties by* ***experiences*** *and then to proceed more slowly to hypotheses for the explanation of them.*

Isaac Newton

Lancaster Middleware Group

- Facilitate development of **new distributed systems**
  - Abstractions?
  - Mechanisms?
  - Exotic environments: MANETs, WSN, routers, …

Lancaster Middleware Group

- Facilitate development of **new distributed systems**
  - Abstractions?
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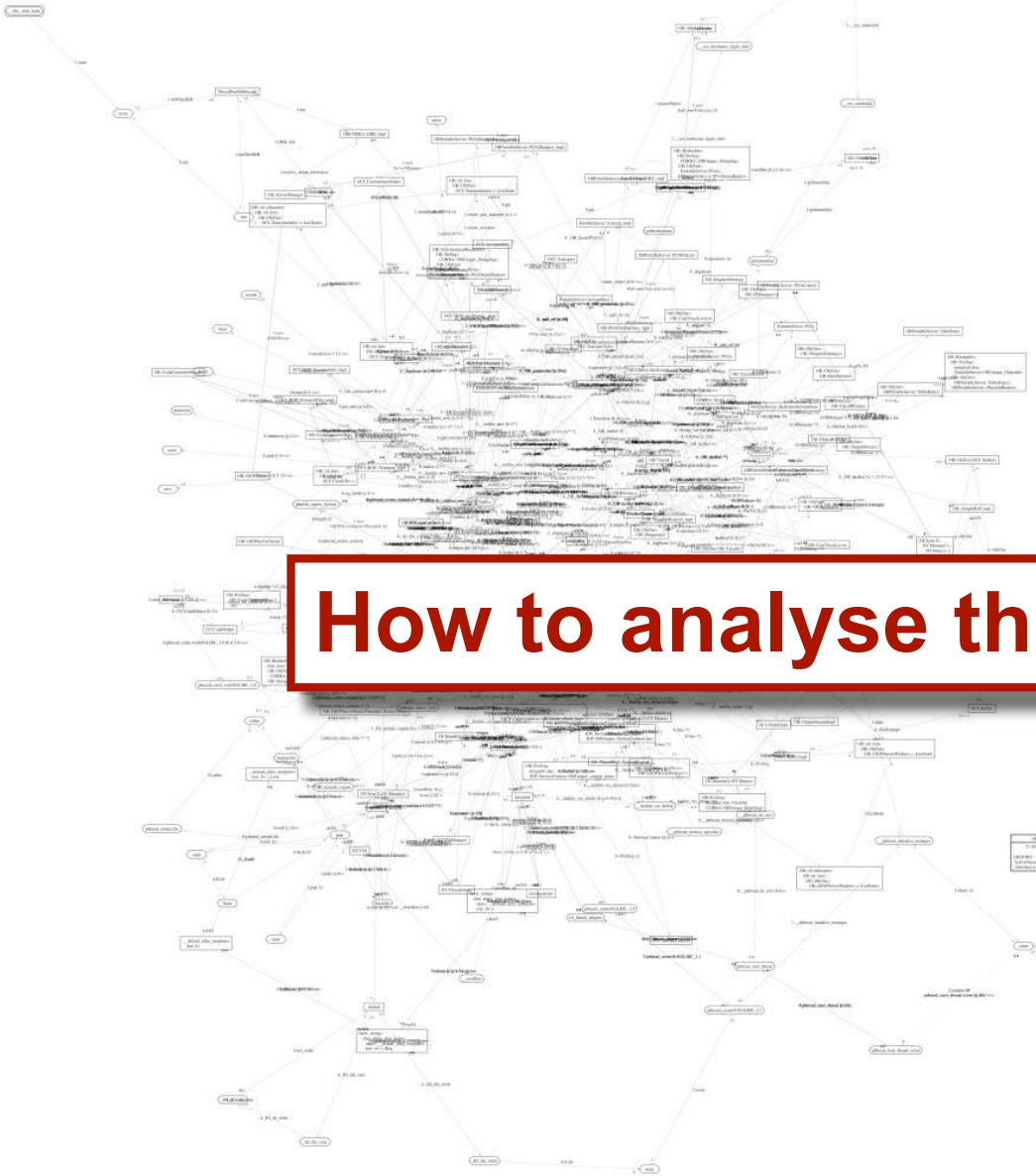
  - Exotic environments: MANETs, WSN, routers, …

- Flip-side: study of **existing middleware**
  - Emergent structures?
  - Development practices?
  - How to ease refactoring / dissemination?

Example: one CORBA request



ORBacus Request Processing

one request,
2065 individual invocations,
over 50 C-functions and 140 C++ classes.

How to analyse this?

Outline

- **Why** reverse engineering middleware?
- Our approach: software "**interferometry**"
- Does it work? **A case study**

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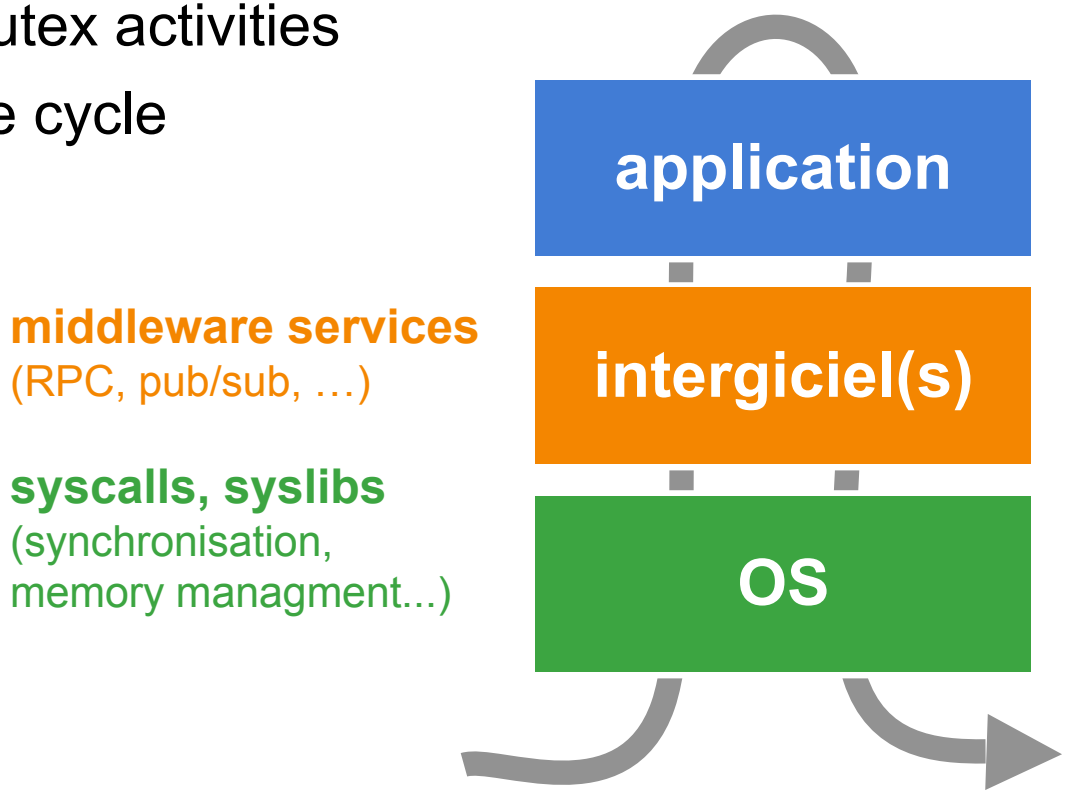
Why?

- Original goal
  - Control non-determinism in industry grade middleware
  - Observation of mutex activities
  - Link to request life cycle



Why?

- Original goal
  - Control non-determinism in industry grade middleware
  - Observation of mutex activities
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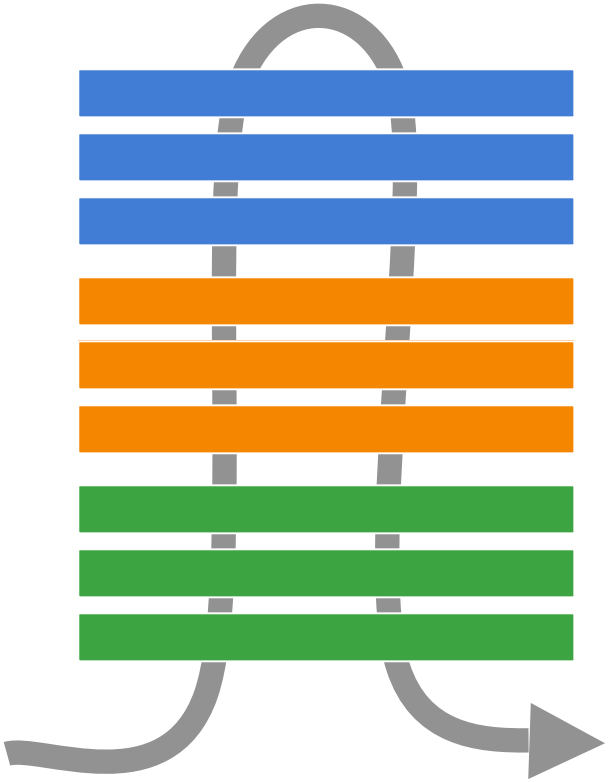
- Complex & layered system
- Hard to observe and analyse
  - **P1: Large behavioural data-set**
  - **P2: Cross-layer entangling**



P1: Large behavioural data-sets

- Example: **Globus**
- **Huge piece of** software (3.9.x)

  123,839 lines in Java (without reused libraries)

  (1,908,810 lines in C/C++, including reused libraries)
- **Many libraries** layered

  XML, WSDL (Descr. Lang), WSRF (Resource Fwork)

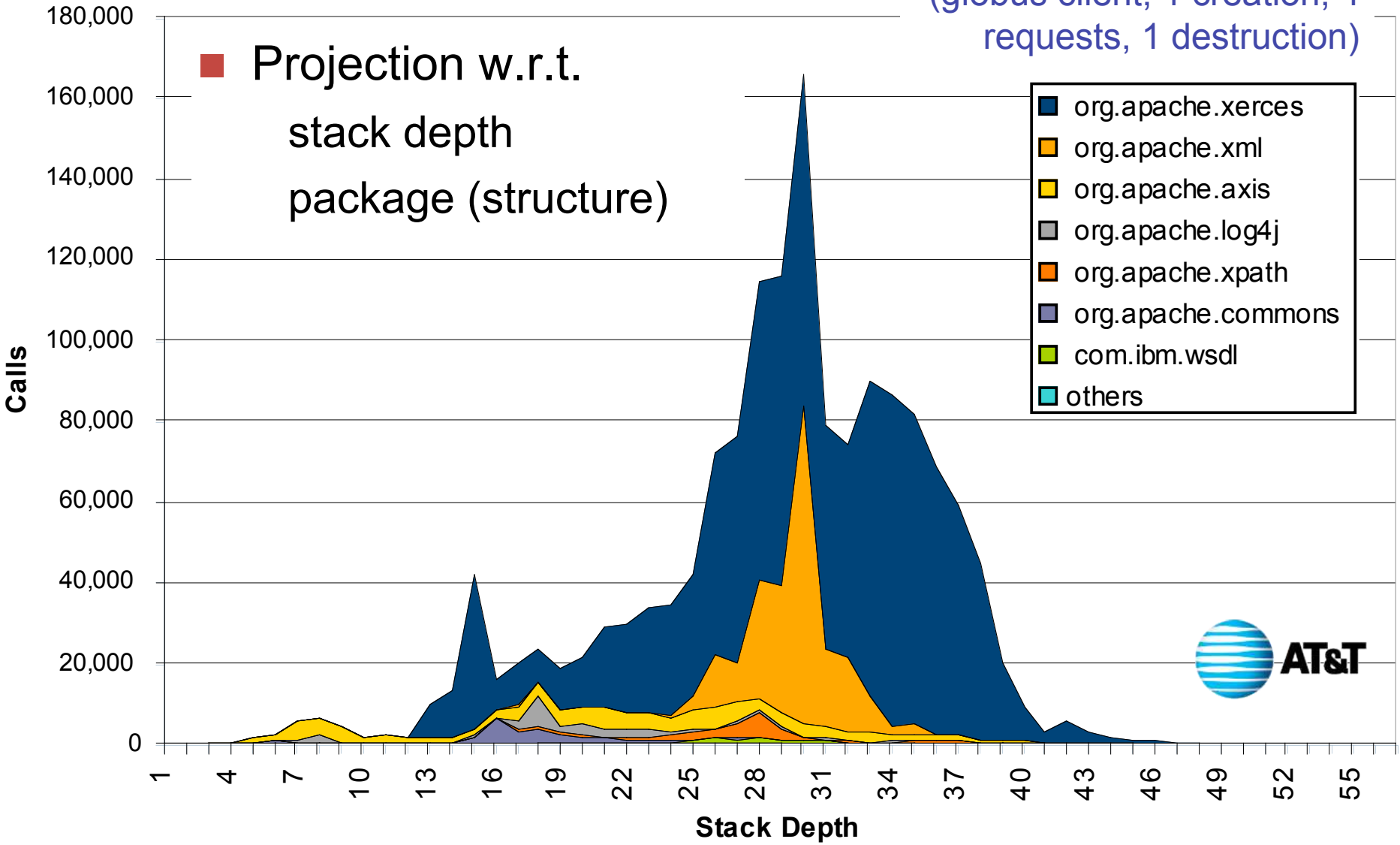
  Axis (SOAP), Xerces (XML Parsing), com.ibm.wsdl
- Java: **exhaustive tracing** (outside the JVM libs)

  client : **1,544,734** local method call (sic)

  server : **6,466,652** local method calls (sic) [+time out]

P1: Large behavioural data-sets

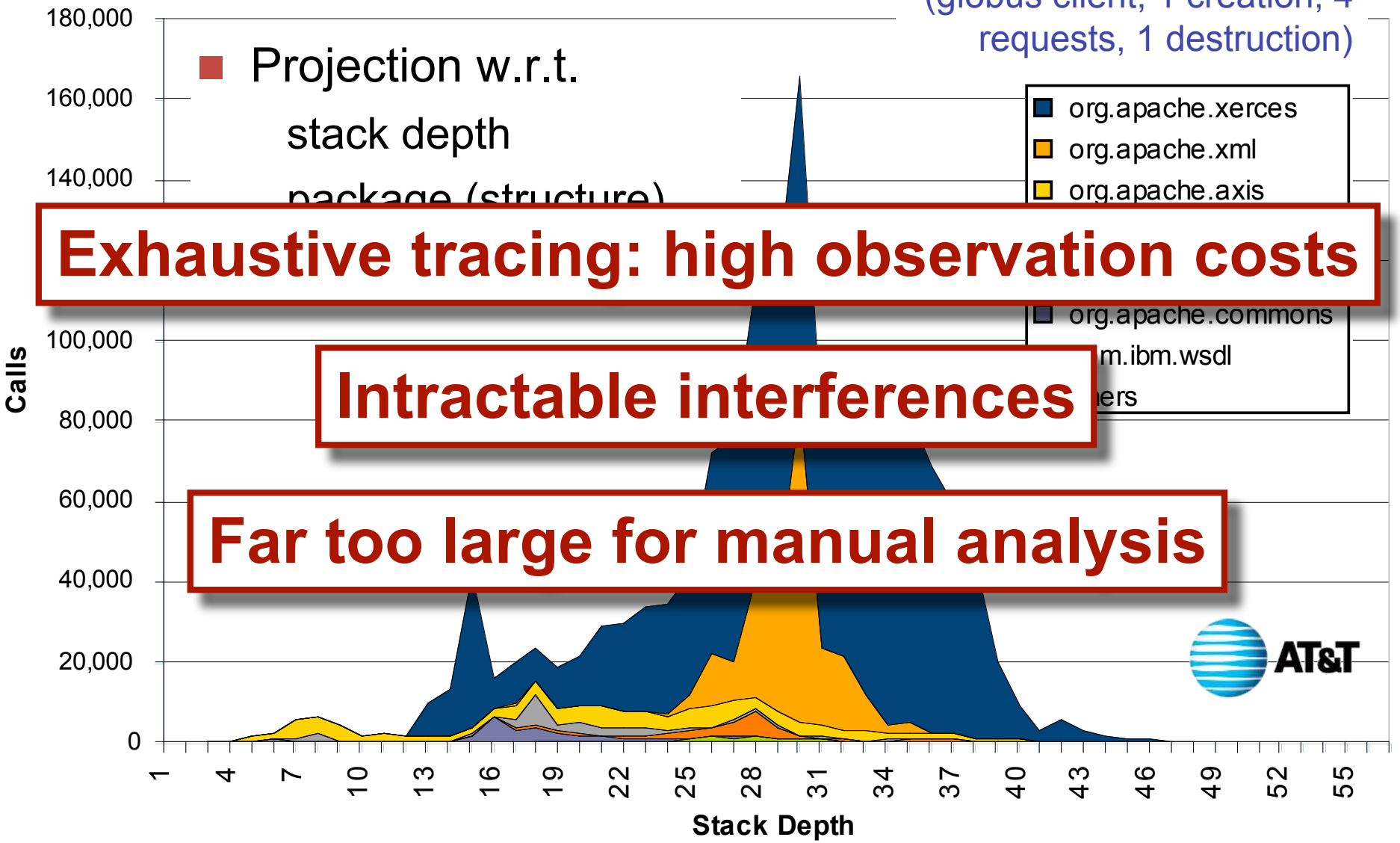
(globus client, 1 creation, 4 requests, 1 destruction)



P1: Large behavioural data-sets

(globus client, 1 creation, 4 requests, 1 destruction)

- Projection w.r.t.
  - stack depth
  - package (structure)



Exhaustive tracing: high observation costs

Intractable interferences

Far too large for manual analysis

P2: Cross-layer entangling

```
int main () {
   pthread_t threadN1, threadN2 ;
   pthread_create(&threadN1, NULL, dummy1, NULL) ;
   pthread_create(&threadN2, NULL, dummy2, NULL) ;
   pthread_join  ( threadN1, NULL) ;
   pthread_join  ( threadN2, NULL) ;
};
```

P2: Cross-layer entangling

dummy1

dummy2

```
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?

OS

observation by tracing

P2: Cross-layer entangling

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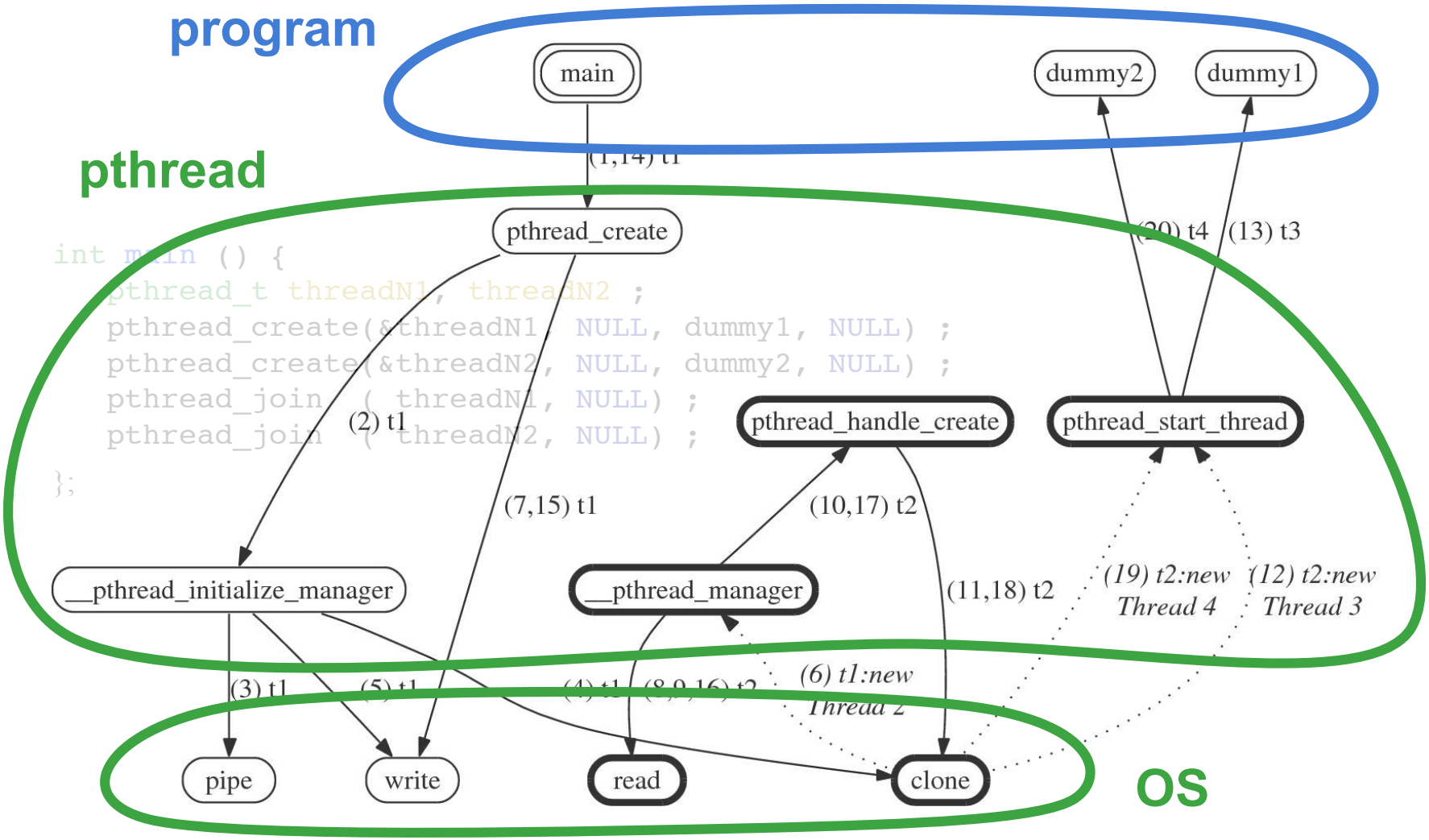
};
```

Can we reconstruct main's behaviour?

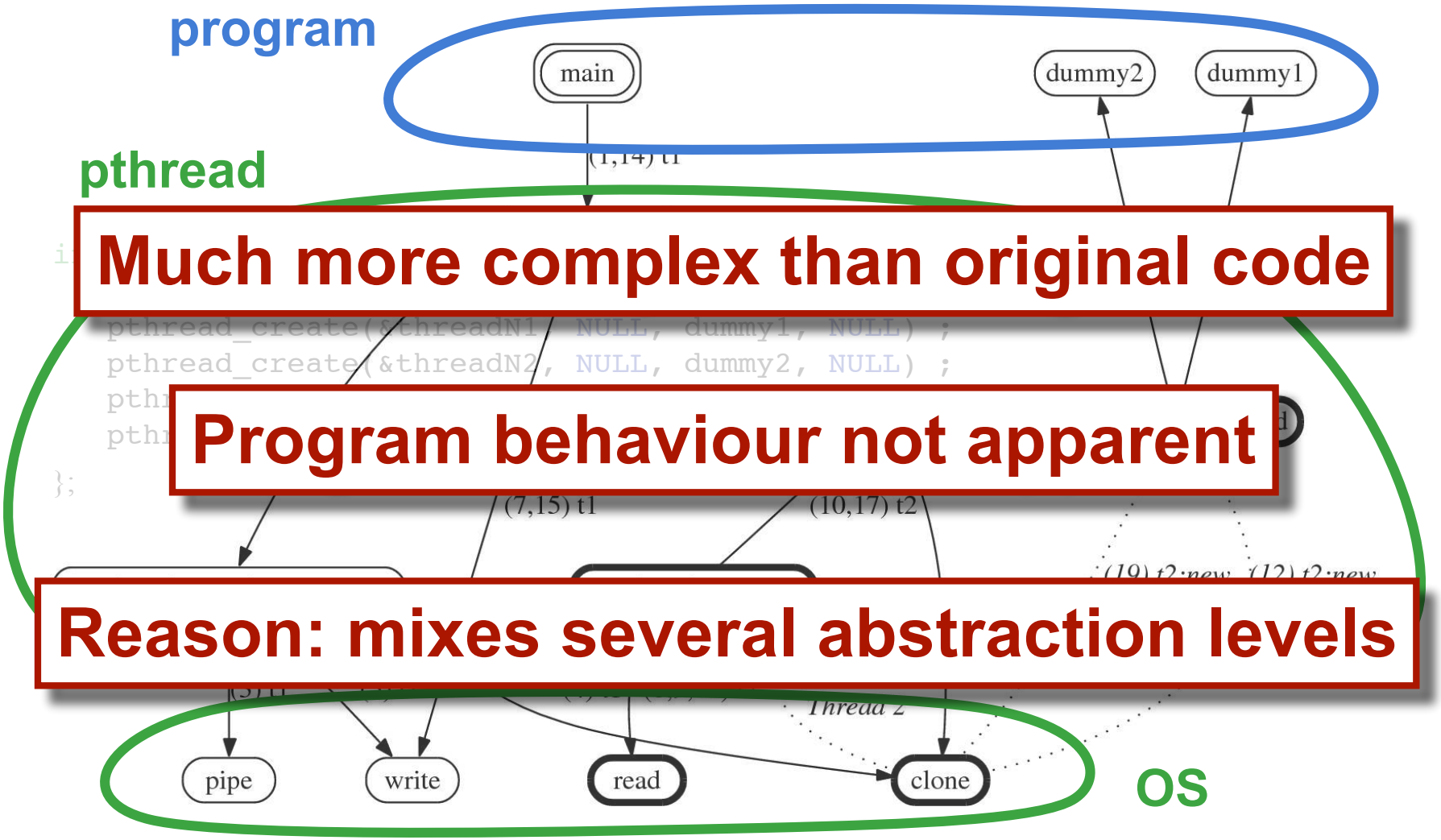
OS

observa by tracing

P2: Cross-layer entangling



P2: Cross-layer entangling



Outline

- **Why** reverse engineering middleware?
- Our approach: software "**interferometry**"
- Does it work? **A case study**

Approach: “interferometry”

- **Limit** observation costs: **more for less**
  - capture stack traces (more)
  - limit observation points to component boundaries (less)
- **Filter** out unneeded data: “interferometry”
  - graph manipulation script language
  - reusable filters

vs.

More for less

```
#0  0x405c8f20 in send () from /lib/libpthread.so.0
#1  0x4015804a in omni::tcpConnection::Send ()
#2  0x4011364c in omni::giopStream::sendChunk ()
[..]
#8  0x400bdb0a in omniAsyncWorker::run ()
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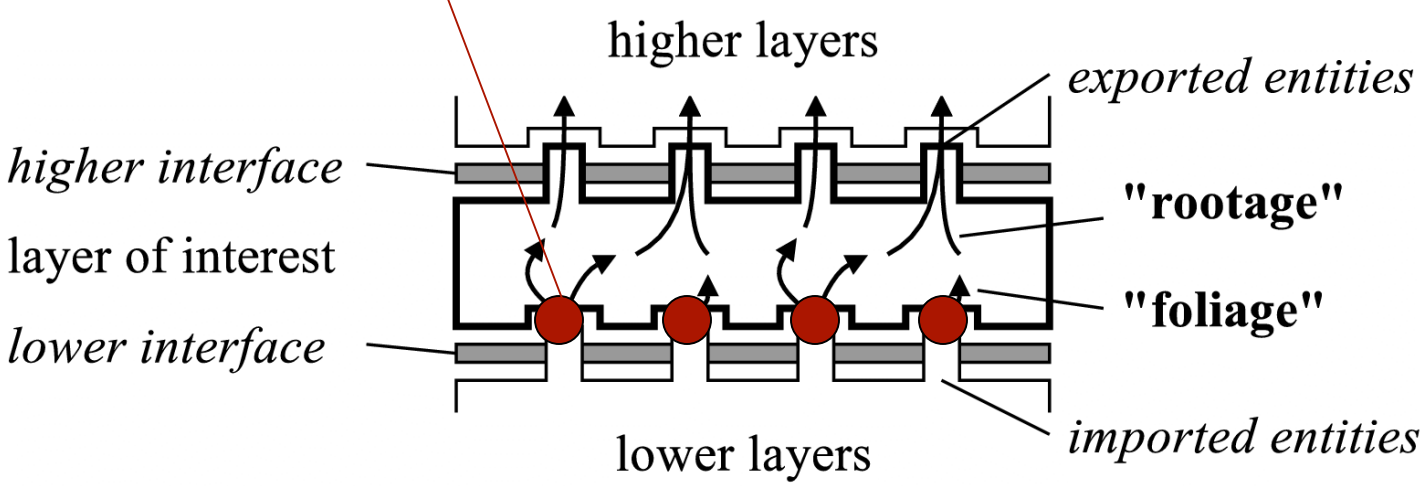
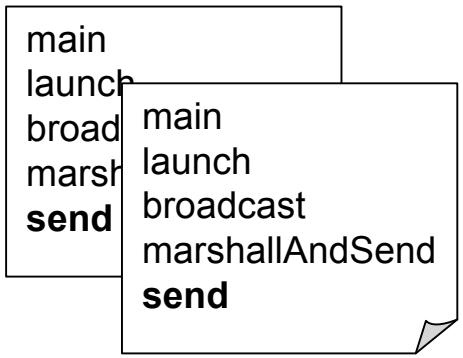
```

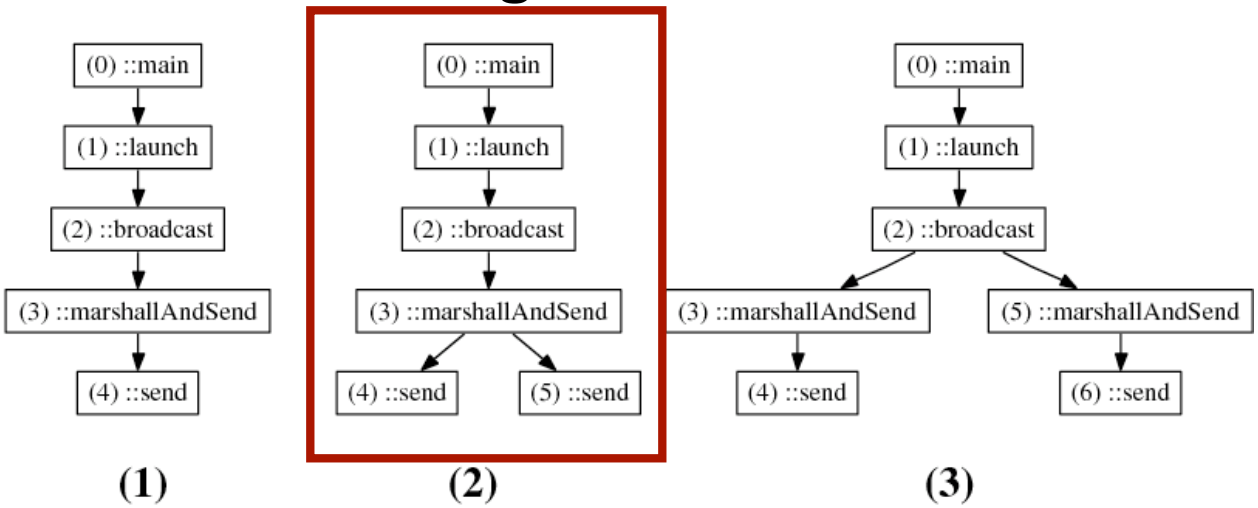


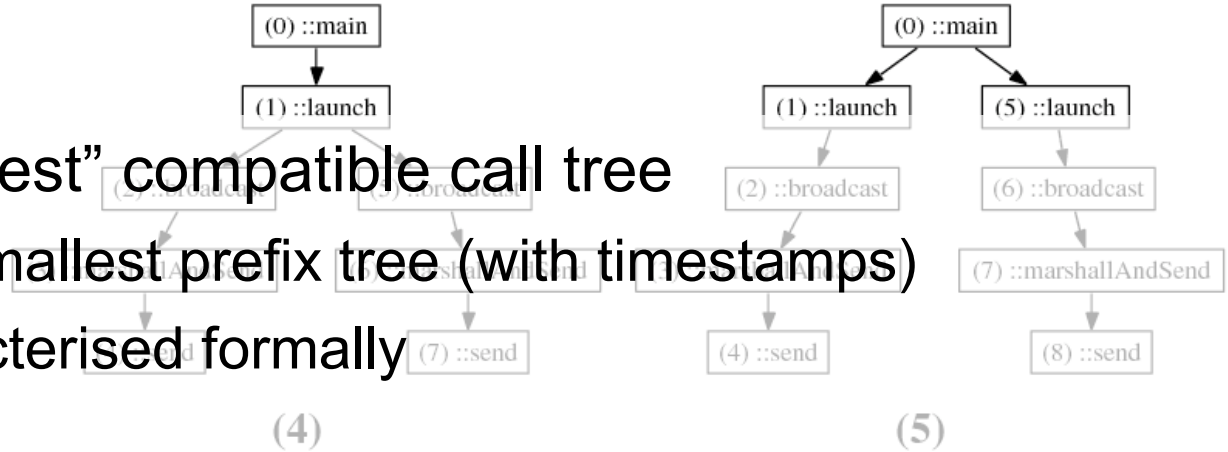
Reconstructing a call tree

- Problem: stack traces are **ambiguous**



2 identical traces





- Choice: “smallest” compatible call tree
  - a variant of smallest prefix tree (with timestamps)
  - can be characterised formally

Graph manipulation filters

Provides **variables** to store intermediary results

A number of graph **operators**

- **selection**

  `put ::pthread_create* G CREATE`

- **recursive extension**

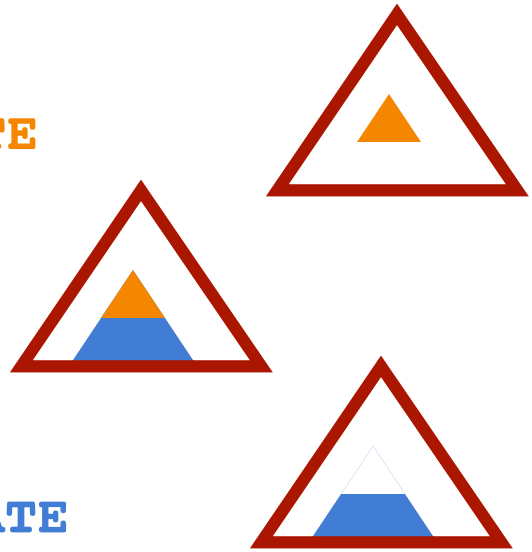
  `forward CREATE G`

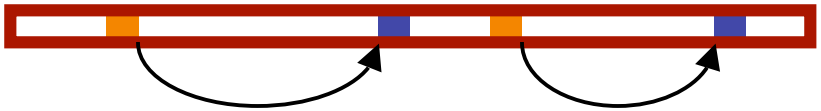
- **boolean algebra**

  `remove ::pthread_create* CREATE`

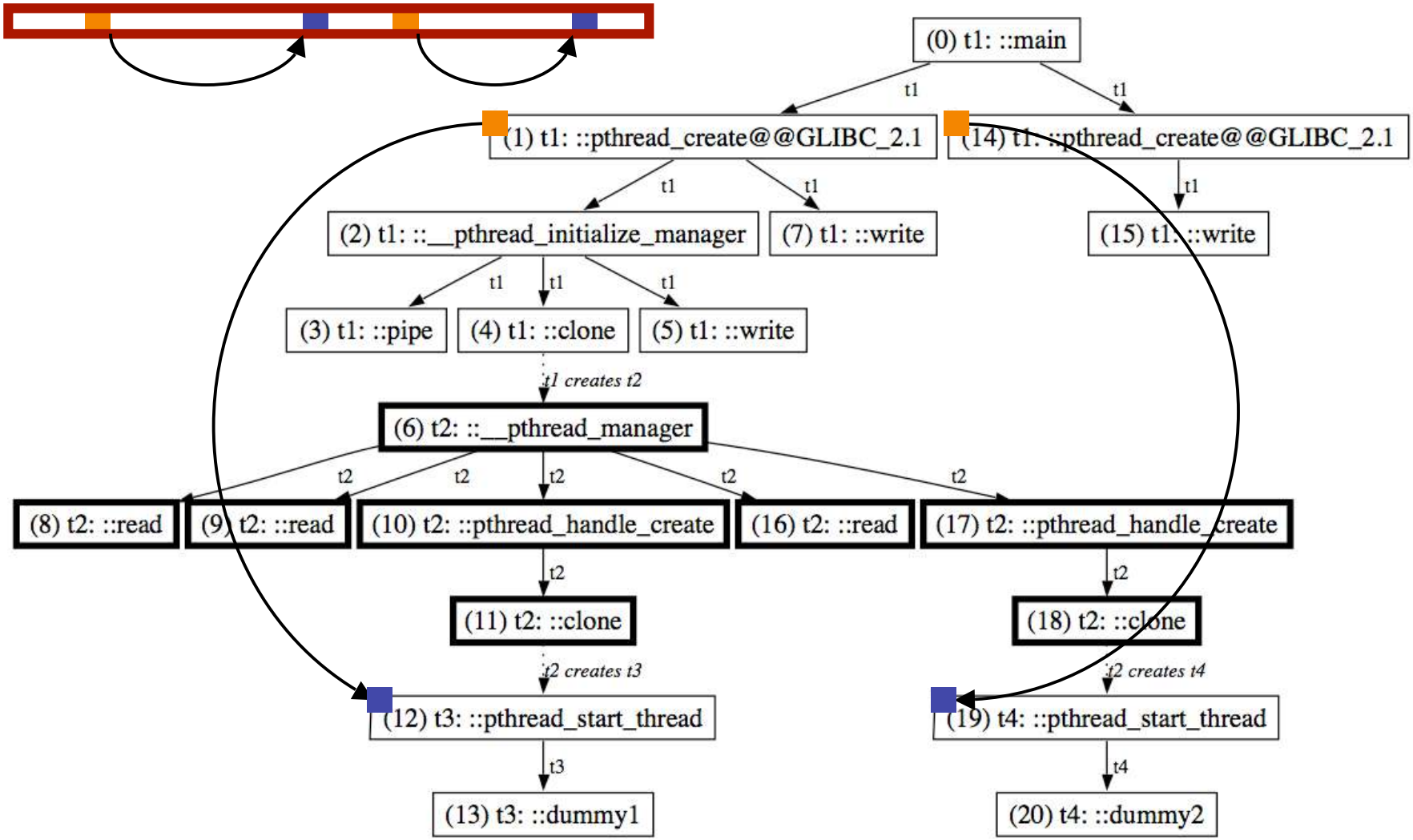
- **temporal operations**

  `fuse ::pthread_create* ::pthread_start_thread* G`





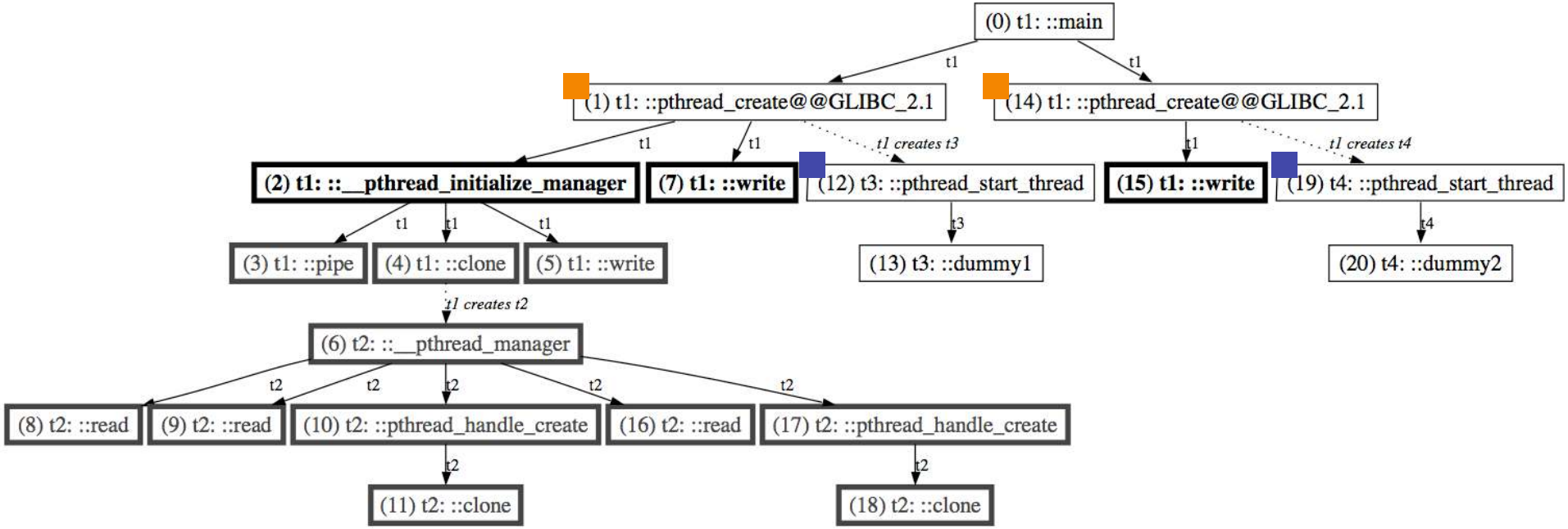
Revisiting pthread




```
fuse ::pthread_create* ::pthread_start_thread* G
```

Revisiting pthread

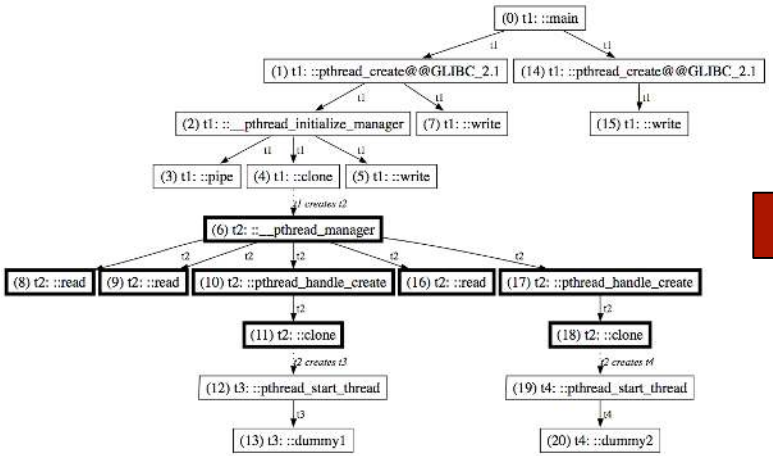
- ‘Reconstructing’ data-flow from temporal succession

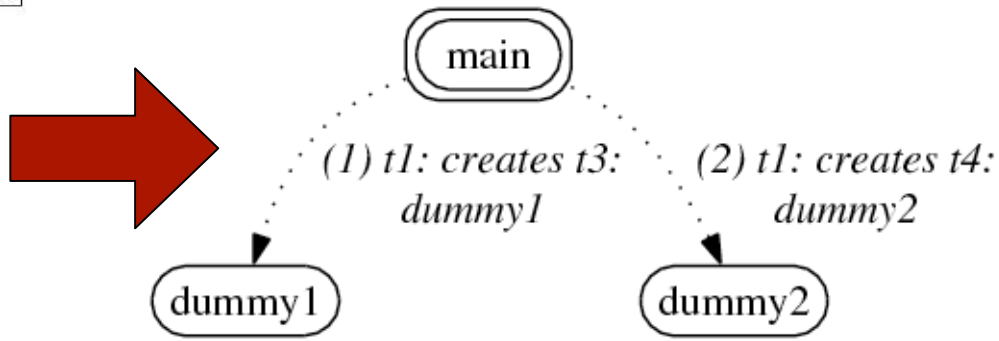



```
fuse ::pthread_create* ::pthread_start_thread* G
```

Revisiting pthread

```
fuse     ::pthread_create* ::pthread_start_thread* G
put      ::pthread_create* G CREATE
forwN    1 CREATE G
remove   ::pthread_create* CREATE
remove   ::pthread_start_thread* CREATE
forward CREATE G
exclude CREATE G
absPatern ::pthread_create* G
absPatern ::pthread_start_thread* G
```



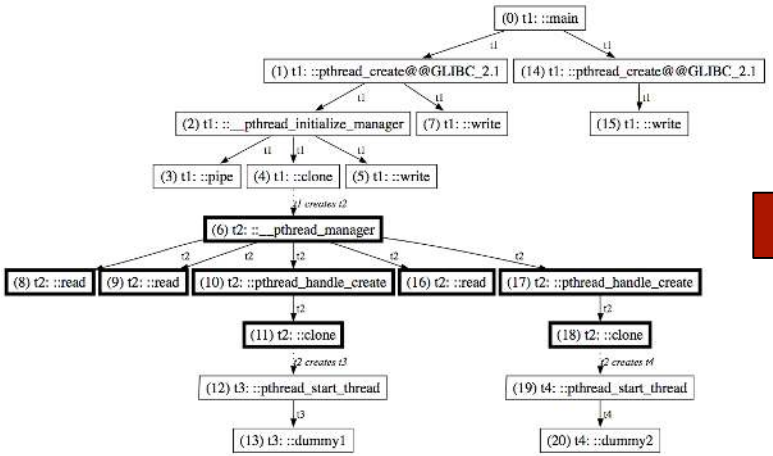


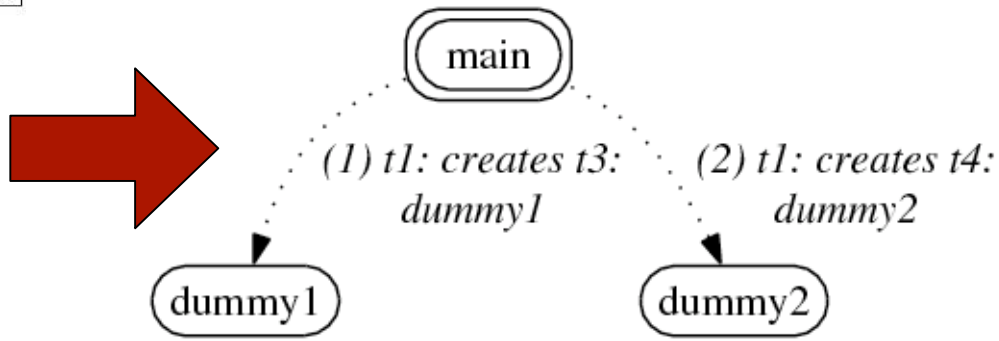
Revisiting pthread

```
fuse     ::pthread_create* ::pthread_start_thread* G
put      ::pthread_create* G CREATE
forwN    1 CREATE G
```

Generic script: applies to any pthread code

```
exclude CREATE G
absPatern ::pthread_create* G
absPatern ::pthread_start_thread* G
```





Case study

- 3 C/C++ industry-grade CORBA products

  ORBacus, **omniORB**, **TAO**

- Set up

  ~ 60 breakpoints (locks, memory, threading, callbacks)

  one ping-pong request

  1GHz Pentium III, Linux kernel 2.4, gdb 5.1-1

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  one ping-pong request

  1GHz Pentium III, Linux kernel 2.4, gdb 5.1-1

- Observation **overheads** (Orbacus)

  non-instrumented: < 1s

  fully instrumented: 1h 2m 11s

  lock tracing disabled during initialisation: 4m 53s

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Stack capture speedup

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#1  0x4015804a in omni::tcpConnection::Send ()
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```

ORB	threads	traces	frames	invocations	invocations/traces
ORBACUS 4.1	8	658	9178	2066	3.13
OMNIORB 4	7	1828	16807	3088	1.68
TAO 1.2.1	6	512	11260	1352	2.64

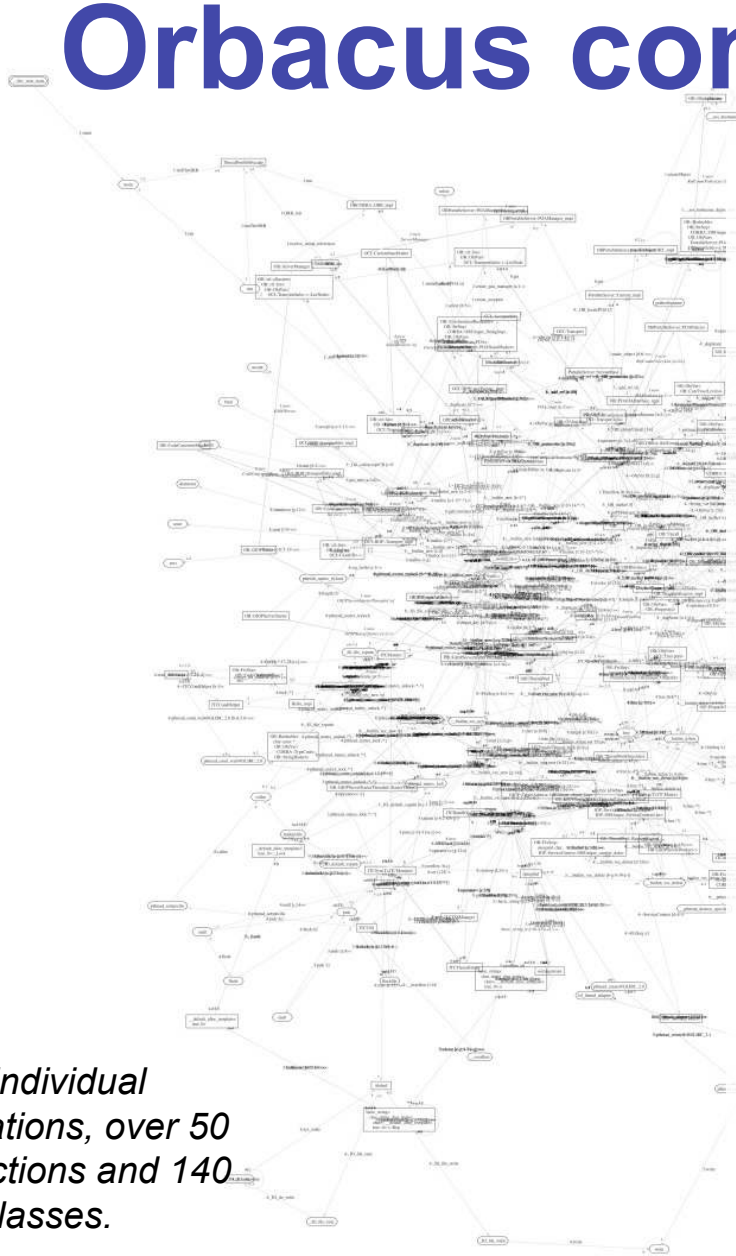
breakpoint activation = cost

reconstructed tree = added value

ratio = speedup

(with lock tracing disabled during initialisation)

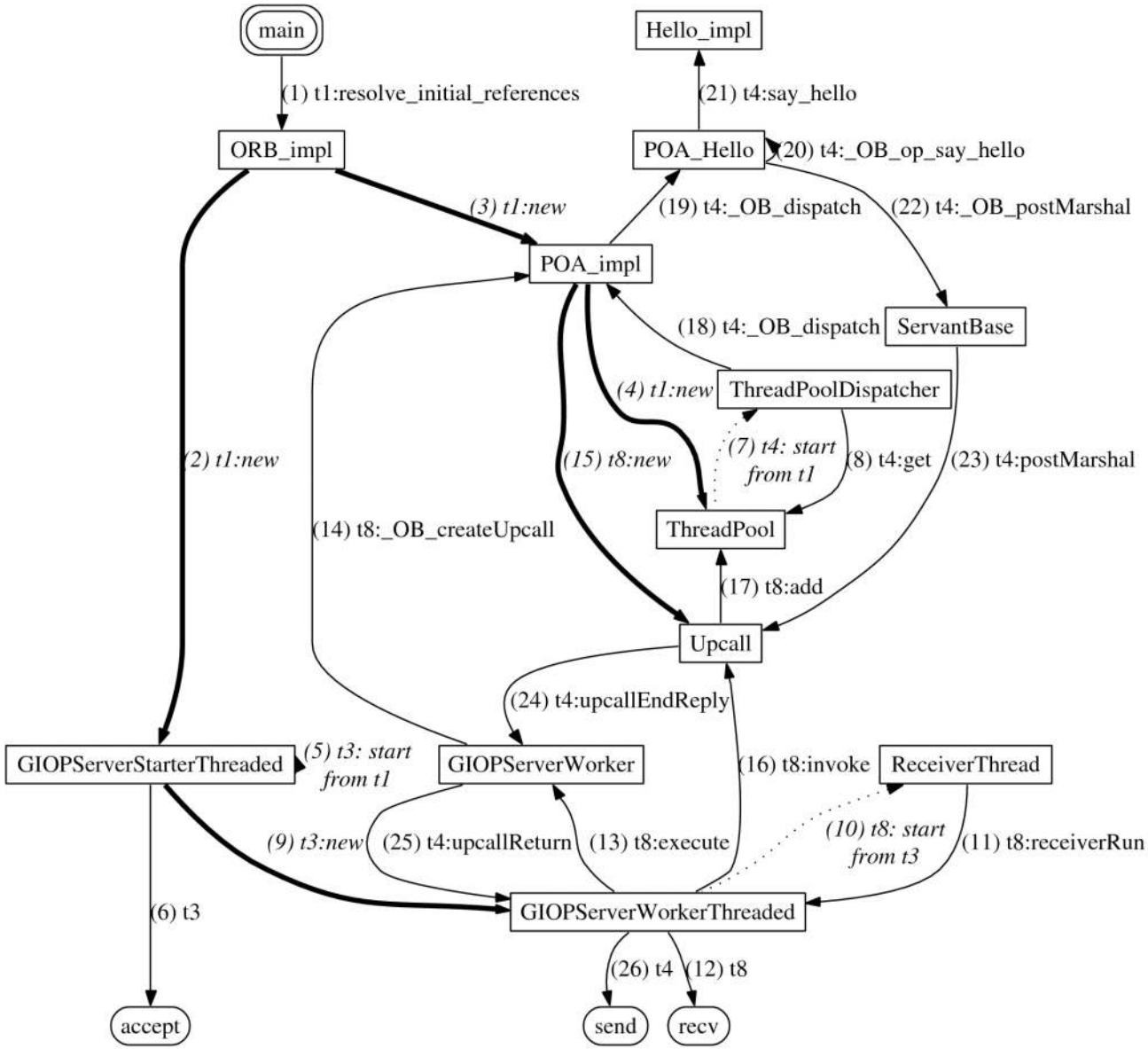
Orbacus complete graph



```
// [remove pthread]
put ::recv'* GlobalGraph R
put ::send'* GlobalGraph R
put Hello_impl::say_hello'* GlobalGraph R
put ::accept'* GlobalGraph R
backward R GlobalGraph
put ::lsf_thread_adapter'* ABS
put JTC* ABS
put OCI::* ABS
put ::__libc_start_main't1-0 ABS
put ::run't1-9 ABS
put OB::ORBControl::initializeRootPOA't1-11 ABS
put OBPortableServer::POAManagerFactory_impl::create_poa_manager't1-12 POA
forwN 3 POA R
add POA ABS
put OBPortableServer::POAPolicies::POAPolicies't1-42 ABS
put OB::DispatchStrategyFactory_impl::* ABS
abstract ABS R
abstract ABS GlobalGraph
remove ::accept't3-882 R
absPatern ::recv't8-828 R
absPatern ::recv't8-1309 R
absPatern ::recv't8-1908 R
put OB::Upcall::Upcall't8-1083 U
backward U GlobalGraph
add U R
put OB::ThreadPool::add't8-1224 TP
put OB::ThreadPool::get't4-1265 TP
backward TP GlobalGraph
add TP R
put OB::GIOPServerStarterThreaded::StarterThread::* ABS2
put OB::DispatchThreadPool_impl::* ABS2
put OB::DispatchRequest_impl::* ABS2
put OB::POAOAInterface_impl::* ABS2
abstract ABS2 R
absPatern OB::GIOPServerWorker::executeRequest't8-* R
```

2065 individual invocations, over 50 C-functions and 140 C++ classes.

Result

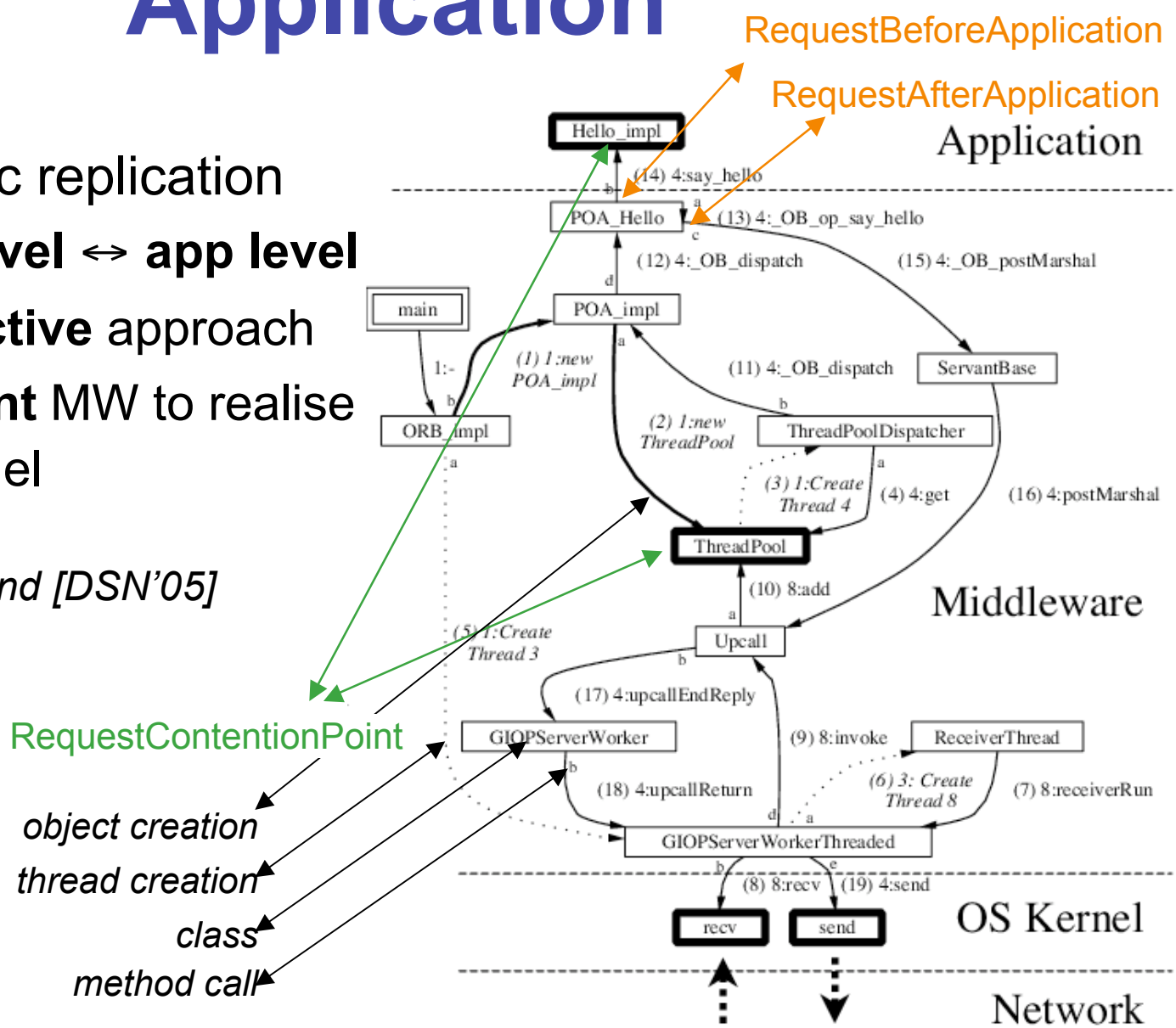


26 individual invocations, 4 C functions, and 23 C++ classes.

Application

- Deterministic replication
  - link **OS level** ↔ **app level**
  - use **reflective** approach
  - **instrument** MW to realise meta-model

ref: *[DSN'03] and [DSN'05]*



Conclusion

- **Pragmatic** approach to dynamic reverse engineering
  - addresses complex layered software
  - minimises interferences by using stack traces
  - reconstruction and graph manipulation for analysis
- Caveat
  - reverse engineering remains a **human** activity
  - constructed graphs provide a roadmap / guide
  - but must be supported by other activities
- Future
  - better analysis of help provided (**user studies**)
  - better formalisation of **consistency** in graph manipulation

(Some) references

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- http://ftaiani.ouvaton.org/7-software/

Thank you

Questions?