Lightweight RPC

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The Three Questions

- What is the problem?
- What is new or different?
- What are the contributions and limitations?

The Structure of Systems

- Monolithic kernels
  - Hard to modify, debug, validate
- Alternative: Fine-grained protection with capabilities
  - Relies on protected procedure calls
  - Is difficult to implement efficiently and to develop for
- Alternative: Small kernels (think Mach)
  - Rely on user-space servers for most functionality
  - But how to communicate between different parts?
- Large-grained protection through machine boundaries
  - Relies on *remote procedure calls* → use with small kernels!

Problem and Approach

- Small kernels use distributed programming models
- But common case of communication is not across net
  - Rather across domains on the same machine

- Optimize for the common case
  - Simple control transfer: use the same thread
  - Simple data transfer: use shared argument stack
  - Simple stubs: optimize for local transfer
  - Design for concurrency: avoid shared data structures

Backgrounder: RPC

By Hank Levy (UW)

Remote Procedure Call

- The basic model for Remote Procedure Call (RPC) described by Birrell and Nelson in 1980
  - Based on work done at Xerox PARC
- Goal was to make RPC look as much like local PC as possible
- Used computer/language support
- There are three components on each side
  - a user program (client or server)
  - a set of *stub* procedures
  - RPC runtime support

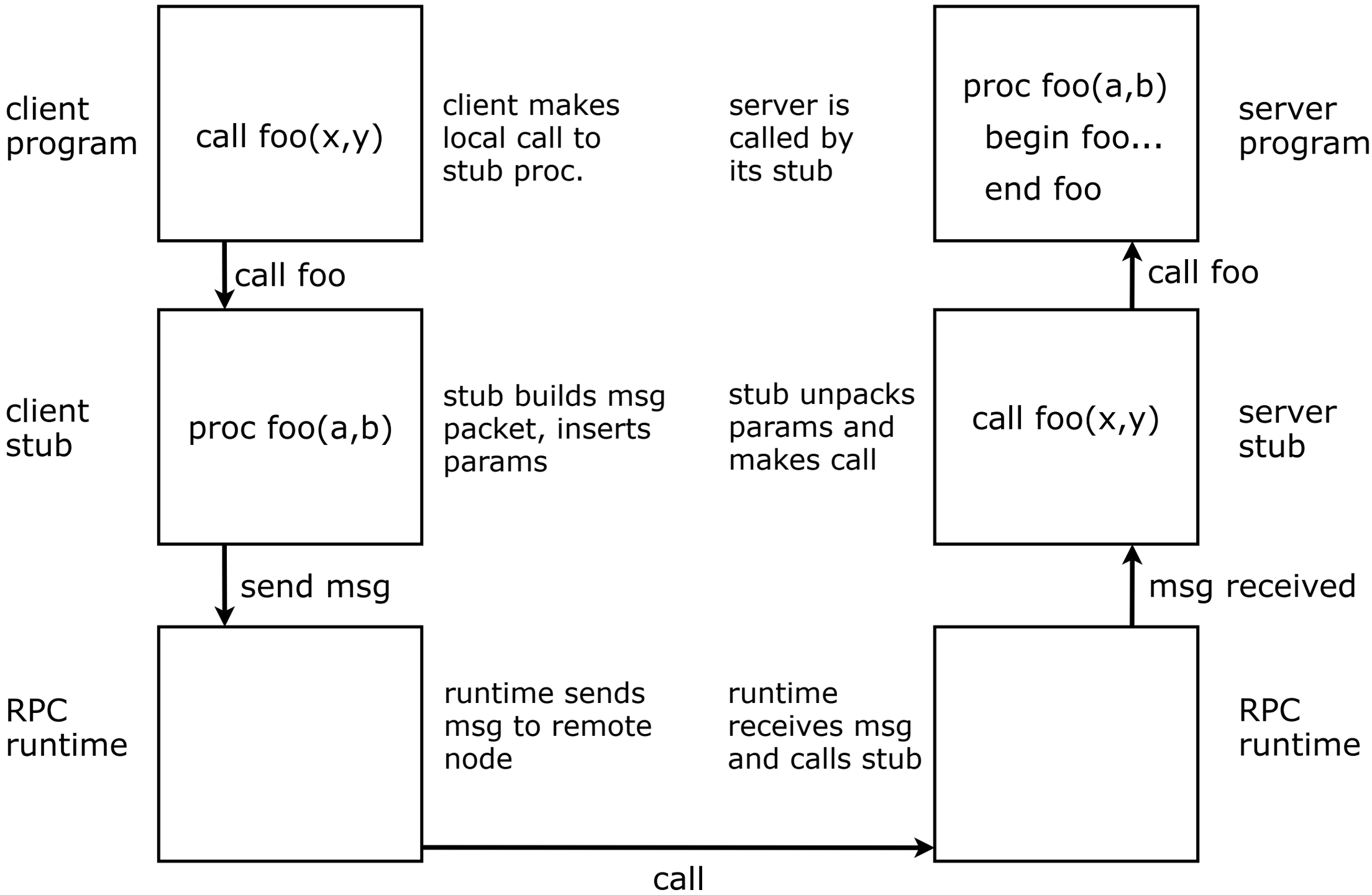
RPC

- Basic process for building a server
  - Server program defines the server's interface using an *interface definition language* (IDL)
  - IDL specifies names, parameters, and types for all client-callable server procedures
  - A *stub compiler* reads the IDL and produces two stub procedures for each server procedure
    - A client-side stub and a server-side stub
  - The server writer writes the server and links it with the server-side stubs; the client writes her program and links it with the client-side stubs
  - The stubs are responsible for managing all details of the remote communication between client and server

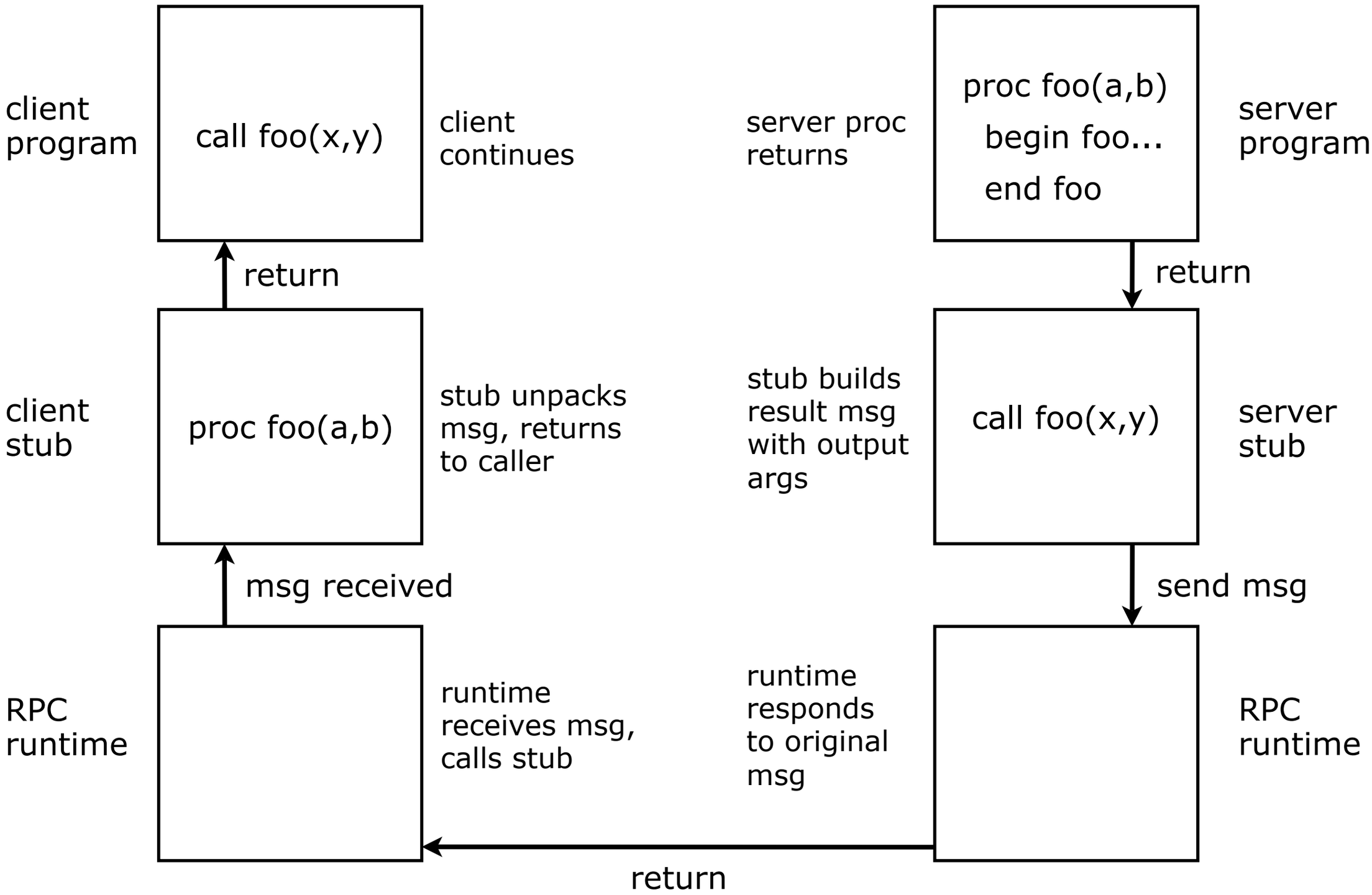
RPC Stubs

- Basically, a client-side stub is a procedure that looks to the client as if it were a callable server procedure
- A server-side stub looks to the server as if it's a calling client
- The client program thinks it is calling the server; in fact, it's calling the client stub
- The server program thinks it's called by the client; in fact, it's called by the server stub
- The stubs send messages to each other to make RPC happen

RPC Call Structure



RPC Return Structure



RPC Binding

- Binding is the process of connecting the client and server
- The server, when it starts up, *exports* its interface, identifying itself to a network name server and telling the local runtime its dispatcher address
- The client, before issuing any calls, *imports* the server, which causes the RPC runtime to lookup the server through the name service and contact the requested server to set up a connection
- The *import* and *export* operations are explicit calls in the code

RPC Marshalling

- Marshalling is the packing of procedure parameters into a message packet
- The RPC stubs call type-specific procedures to marshall (or unmarshall) all of the parameters to the call
- On the client side, the client stub marshalls the parameters into the call packet; on the server side, the server stub unmarshalls the parameters to call the server's procedure
- On return, the server stub marshalls return parameters into the return packet; the client stub unmarshalls return parameters and returns to client

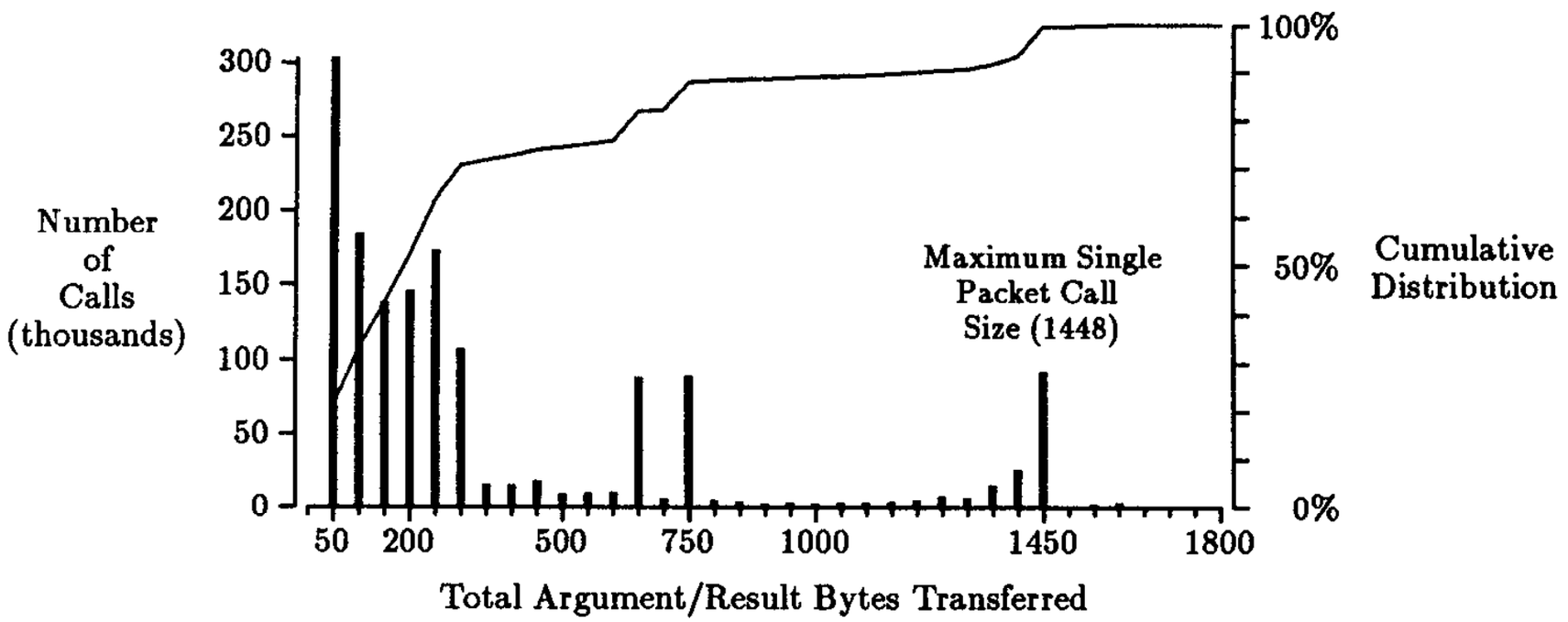
RPC Final

- RPC is the most common model now for communication in distributed applications
- RPC is essentially *language support* for distributed programming
- RPC relies on a *stub compiler* to automatically produce client/server stubs from the IDL server description
- RPC is commonly used, *even on a single node*, for communication between applications running in different address spaces.
  In fact, most RPCs are intra-node.

Back (Well, Forward) to Lightweight RPC

Use of RPC

- Most RPCs are cross-domain but not cross-machine
  - 97% on V, 94.7% on Taos, 99.4% on Sun+NFS
- Most RPCs transfer little data
  - On Taos, 3 procedures account for 75% of all RPCs
- No complex marshalling; byte copy suffices



Overheads of RPC (vs. Null Proc)

- Stub overhead
- Message buffer overhead
- Access validation
- Message transfer
- Scheduling
- Context switch
- Dispatch
- *What about SRC RPC?*

Table II. Cross-Domain Performance (times are in microseconds)

System	Processor	Null (theoretical minimum)	Null (actual)	Overhead
Accent	PERQ	444	2,300	1,856
Taos	Firefly C-VAX	109	464	355
Mach	C-VAX	90	754	664
V	68020	170	730	560
Amoeba	68020	170	800	630
DASH	68020	170	1,590	1,420

Can We Do Better?

- LRPC: Combination of *protected* and *remote* proc calls
  - Execution model: protected procedure call
    - Call to server made through kernel trap
    - Kernel validates caller, creates linkage (?), dispatches concrete thread to server
    - Procedure returns through kernel
  - Semantics: remote procedure call
    - Servers export interfaces
    - Clients bind interfaces
    - Clients and servers reside in large-grained protection domains
- What is the trade-off when compared to regular RPC?

LRPC Binding

- Overall comparable to regular RPC
  - Server exports interface to name server
  - Client imports interface
- Details differ due to high degree of cooperation
  - *Procedure descriptor* (PD)
    - Entry address, number of simultaneous calls, size of *A-stack*
      - Pair-wise shared memory for arguments and return values
  - *Linkage record*
    - Record of caller's return address
  - *Binding object*
    - Capability for accessing the server

LRPC Calls

- Client stub sets up A-stack, calls kernel
- Kernel
  - Verifies binding object & procedure identifier, locates PD
  - Verifies A-stack, locates linkage record
  - Ensures that A-stack & linkage record are unused
  - Records caller's return address in linkage record
  - Pushes linkage record on per-thread stack — why?
  - Locates execution stack (*E-stack*) in server's domain
  - Updates thread's stack pointer to use E-stack
  - Changes virtual memory registers
  - Performs upcall into server

LRPC Calls (cont.)

- Return through kernel
  - No verification of rights, data structures
  - No explicit message passing
- Call-by-reference requires local reference — why?
- E-stacks dynamically associated with A-stacks
  - Association performed on first call with given A-stack
  - E-stacks reclaimed when supply runs low
  - Why no static association?

More Details

- Stubs blur boundaries of traditional RPC layers
  - Direct invocation of server stubs, no message dispatch
  - Simple LRPCs require one procedure call, two returns (?)
- LRPC designed for multi-processors
  - Each A-stack queue guarded by its own lock
  - Protection domains (processes) cached on idle processors
    - Processors changed on LRPC (in both directions)
    - Context switch only performed when domain not cached
      - Forced context switches are counted to help with scheduling
    - Generalized technique (Amoeba & Taos cache blocked threads)

LRPC Argument Copying

- Copying performed in stubs, not in kernel
  - 4 times for RPC, once for LRPC in common case
- But shared memory allows for asynchronous changes
  - Extra copy for immutable parameters
- Constraint checks folded into copy operation

Table III. Copy Operations for LRPC versus Message-Based RPC

Operation	LRPC	Message passing	Restricted message passing
Call (mutable parameters)	A	ABCE	ADE
Call (immutable parameters)	AE	ABCE	ADE
Return	F	BCF	BF

Code	*Copy operation*
A	Copy from client stack to message (or A-stack)
B	Copy from sender domain to kernel domain
C	Copy from kernel domain to receiver domain
D	Copy from sender/kernel space to receiver/kernel domain
E	Copy from message (or A-stack) into server stack
F	Copy from message (or A-stack) into client's results

Performance of LRPC

Table IV. LRPC Performance of Four Tests (in microseconds)

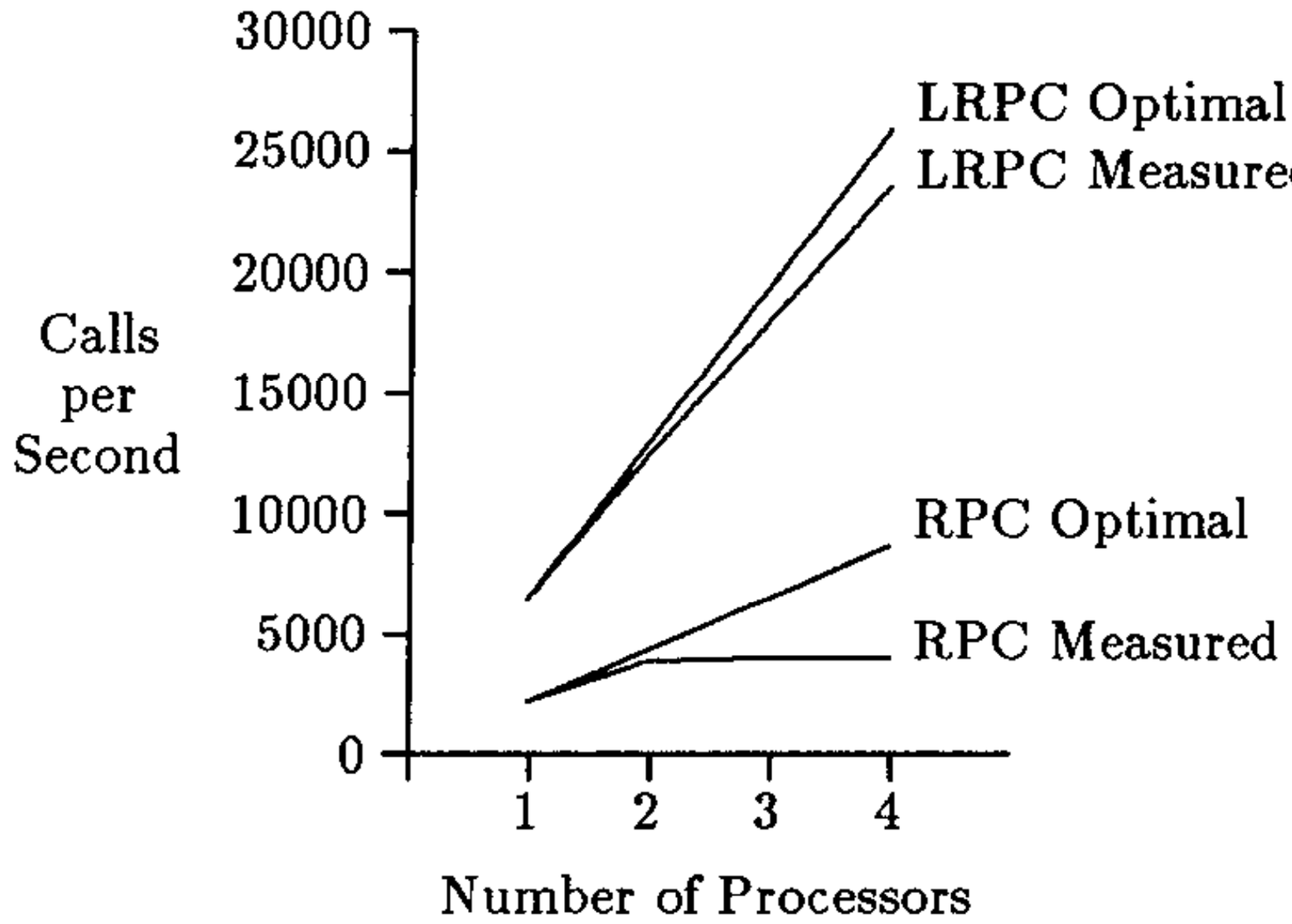
Test	Description	LRPC/MP	LRPC	Taos
Null	The Null cross-domain call	125	157	464
Add	A procedure taking two 4-byte arguments and returning one 4-byte argument	130	164	480
BigIn	A procedure taking one 200-byte argument	173	192	539
BigInOut	A procedure taking and returning one 200-byte argument	219	227	636

Table V. Breakdown of Time (in microseconds) for Single-Processor Null LRPC

Operation	Minimum	LRPC overhead
Modula2+ procedure call	7	—
Two kernel traps	36	—
Two context switches	66	—
Stubs	—	21
Kernel transfer	—	27
Total	109	48

Incl. ~43 TLB misses

Performance of LRPC (cont.)



* Why does RPC level off at 2 processors?

The Uncommon Cases

- LRPC still supports cross-machine RPC
  - Detected in first instruction of client stub
- A-stacks are either statically sized or size of ethernet packet (when args are variably sized)
  - Stubs use out-of-band memory for larger arguments
- Domain termination integrated with LRPC
  - Binding objects are revoked
  - Threads returns to client domain (raising exception)
  - Linkage records of terminating domain invalidated
- Threads can be recreated in client
  - Addresses server capturing a client's thread

What Do You Think?