The RPC abstraction

- **Procedure calls well-understood mechanism**
  - Transfer control and data on single computer
- **Goal: Make distributed programming look same**
  - Code libraries provide APIs to access functionality
  - Have servers export interfaces accessible through local APIs
- **Implement RPC through request-response protocol**
  - Procedure call generates network request to server
  - Server return generates response

RPC Failure

- **More failure modes than simple procedure calls**
  - Machine failures
  - Communication failures
- **RPCs can return "failure" instead of results**
- **What are possible outcomes of failure?**
  - Procedure did not execute
  - Procedure executed once
  - Procedure executed multiple times
  - Procedure partially executed
- **Generally desired semantics: at most once**

Implementing at most once semantics

- **Danger: Request message lost**
  - Client must retransmit requests when it gets no reply
- **Danger: Reply message may be lost**
  - Client may retransmit previously executed request
  - Okay if operations are idempotent, but many are not (e.g., process order, charge customer, ...)
  - Server must keep "replay cache" to reply to already executed requests
- **Danger: Server takes too long to execute procedure**
  - Client will retransmit request already in progress
  - Server must recognize duplicate—can reply "in progress"

Server crashes

- **Danger: Server crashes and reply lost**
  - Can make replay cache persistent—slow
  - Can hope reboot takes long enough for all clients to fail
- **Danger: Server crashes during execution**
  - Can log enough to restart partial execution—slow and hard
  - Can hope reboot takes long enough for all clients to fail
- **Can use "cookies" to inform clients of crashes**
  - Server gives client cookie which is time of boot
  - Client includes cookie with RPC
  - After server crash, server will reject invalid cookie

Parmeter passing

- **Different data representations**
  - Big/little endian
  - Size of data types
- **No shared memory**
  - No global variables
  - How to pass pointers
  - How to garbage-collect distributed objects
- **How to pass unions**

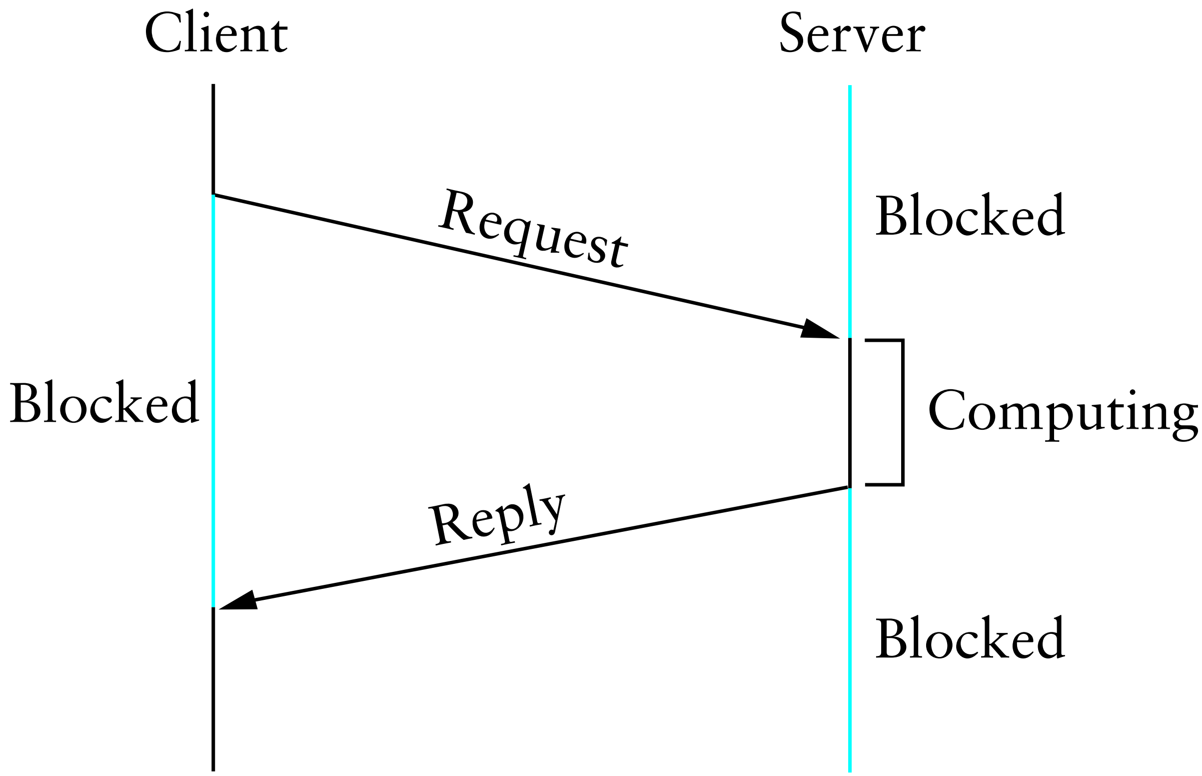
Interface Definition Languages

- **Idea: Specify RPC call and return types in IDL**
- **Compile interface description with IDL compiler. Output:**
  - Native language types (e.g., C/Java/C++ structs/classes)
  - Code to **marshal** (serialize) native types into byte streams
  - **Stub** routines on client to forward requests to server
- **Stub routines handle communication details**
  - Helps maintain RPC transparency, but
  - Still have to bind client to a particular server
  - Still need to worry about failures

Plan for rest of lecture

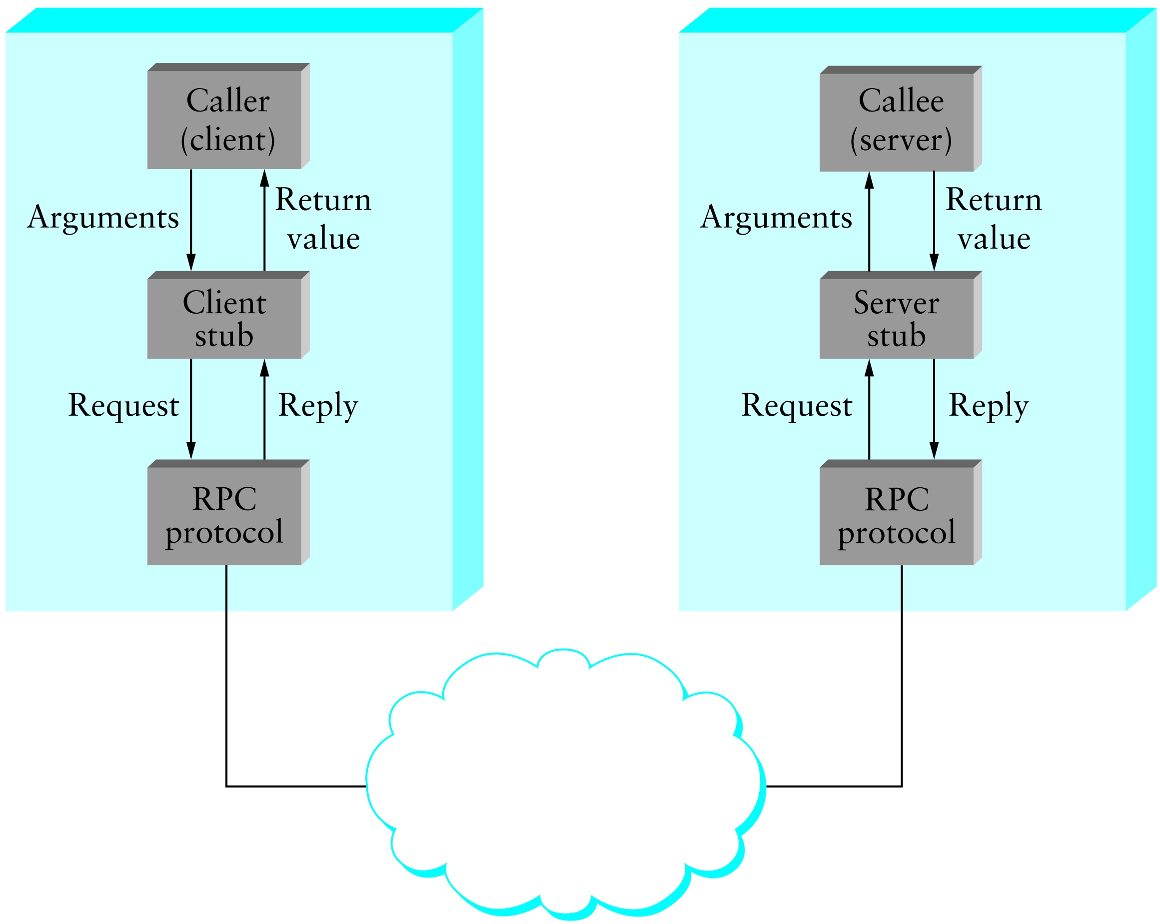
- **Look at “fake” RPC protocol from textbook**
  - Has some nice properties neglected by SunRPC
- **Gloss over a few standards**
- **Look at SunRPC, which you will use for next lab**
  - *De facto* standard for many protocols
  - Has advantage of great simplicity

RPC Timeline



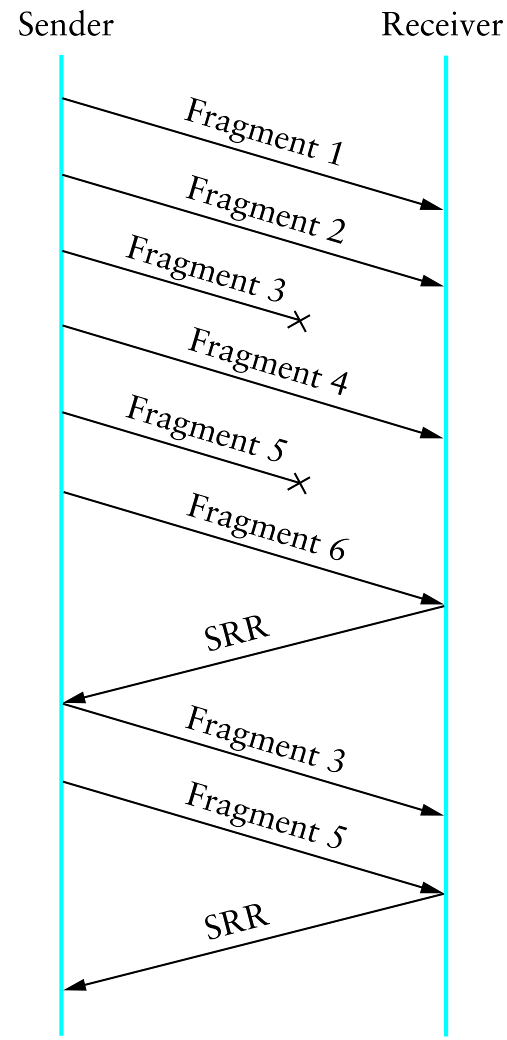
RCP Components

- **Protocol Stack**
  - BLAST: fragments and reassembles large messages
  - CHAN: synchronizes request and reply messages
  - SELECT: dispatches request to the correct process
- **Stubs**



Bulk Transfer (BLAST)

- **Unlike AAL and IP, tries to recover from lost fragments**
- **Strategy**
  - selective retransmission request (SRR)
  - aka partial acknowledgments



BLAST Details

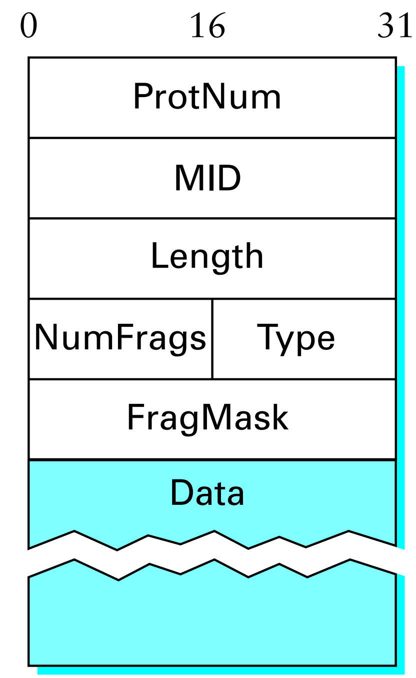
- **Sender:**
  - After sending all fragments, set timer DONE
  - If receive SRR, send missing fragments and reset DONE
  - If timer DONE expires, free fragments

BLAST Details (cont)

- **Receiver:**
  - when first fragments arrives, set timer LAST_FRAG
  - when all fragments present, reassemble and pass up
- **If last fragment arrives but message not complete**
  - send SRR and set timer RETRY
- **If timer LAST_FRAG expires**
  - send SRR and set timer RETRY
- **If timer RETRY expires for first or second time**
  - send SRR and set timer RETRY
- **If timer RETRY expires a third time**
  - give up and free partial message

BLAST Header Format

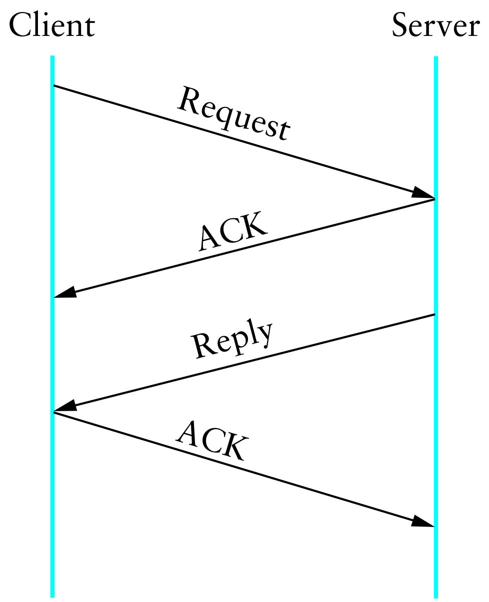
- **MID (message ID) must protect against wrap around**
- **TYPE = DATA or SRR**
- **NumFrags indicates number of fragments**
- **FragMask distinguishes among fragments**
  - if Type=DATA, identifies this fragment
  - if Type=SRR, identifies missing fragments



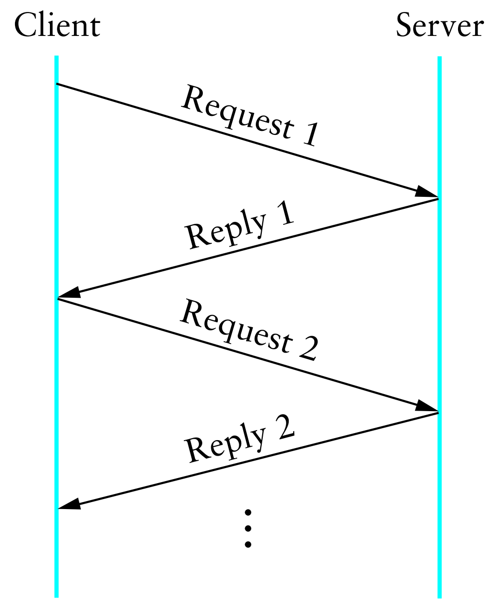
Request/Reply (CHAN)

- Guarantees message delivery
- Synchronizes client with server
- Supports at-most-once semantics

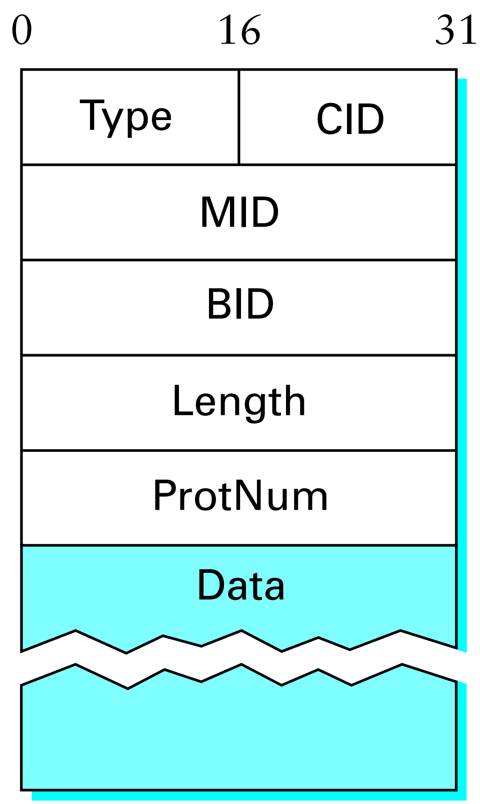
Simple case



Implicit ACKs



Chan header



- **Type = {REQ, REP, ACK, PROBE}**

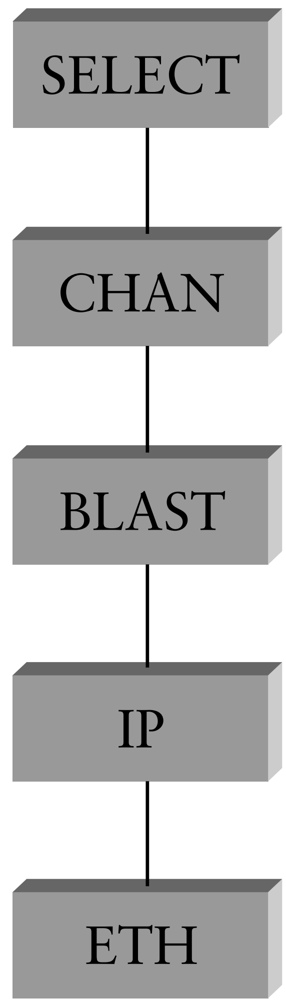
CHAN Details

- **Lost message (request, reply, or ACK)**
  - Set RETRANSMIT timer
  - Use message id (MID) field to distinguish
- **Slow (long running) server**
  - Client periodically sends “are you alive” probe, or
  - Server periodically sends “I’m alive” notice
- **Want to support multiple outstanding calls**
  - Use channel id (CID) field to distinguish
- **Machines crash and reboot**
  - Use boot id (BID) field to distinguish

Dispatcher (SELECT)

- **Just includes appropriate procedure number**
- **Server dispatch to appropriate procedure**
- **Implement concurrency (open multiple CHANs)**
- **Why consider this a separate protocol?**
  - Might want to change procedure addressing w/o changing protocol
- **Address space approaches for procedures**
  - Flat: unique id for each possible procedure
  - Hierarchical: program + procedure number

Summary



Serializing/marshaling data

- **Several standard ways of specifying data formats**
- **ASN.1 – ISO standard. Horrible, horrible, horrible.**
  - Very hard (impossible) to compile automatically
  - Only very expensive commercial compilers exist
  - People compile by hand, get it wrong $\rightarrow$ buffer overruns
- **XML – HTML-like, pseudo-human-readable**
  - Not self describing (external format specification)
  - Hard to parse efficiently
- **XDR – Used by SunRPC**
  - Simple! (my fancy XDR compiler $\sim$2,000 lines of code)
  - Easy to understand, easy to parse quickly
  - Not compatible with arbitrary protocols
  - Not optimally space efficient

Intro to SUN RPC

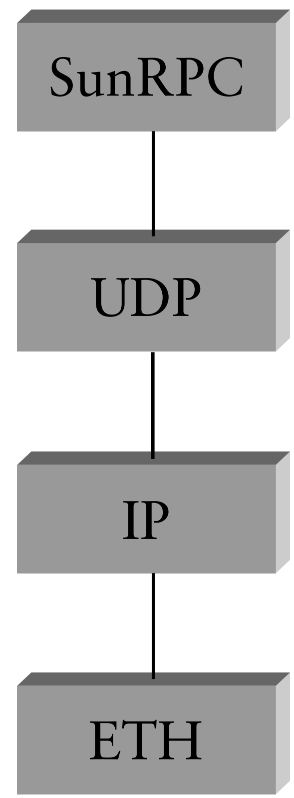
- **Simple, no-frills, widely-used RPC standard**
  - Does not emulate pointer passing or distributed objects
  - Programs and procedures simply referenced by numbers
  - Client must know server—no automatic location
  - Portmap service maps program #s to TCP/UDP port #s
- **IDL: XDR – eXternal Data Representation**
  - Compilers for multiple languages (C, java, C++)

Transport layer

- **Transport layer transmits delimited RPC messages**
  - In theory, RPC is transport-independent
  - In practice, RPC library must know certain properties (e.g., Is transport connected? Is it reliable?)
- **UDP transport: unconnected, unreliable**
  - Sends one UDP packet for each RPC request/response
  - Each message has its own destination address
  - Server needs replay cache
- **TCP transport (simplified): connected, reliable**
  - Each message in stream prefixed by length
  - RPC library does not retransmit or keep replay cache

UDP SunRPC vs. textbook protocol

- **IP implements BLAST-equivalent**
  - except no selective retransmit
- **SunRPC implements CHAN-equivalent**
  - except not at-most-once
- **UDP + SunRPC implement SELECT-equivalent**
  - portmap + UDP dispatches to program (ports bound to programs)
  - SunRPC dispatches to procedure within program



Sun XDR

- **"External Data Representation"**
  - Describes argument and result types:

```
struct message {
  int opcode;
  opaque cookie[8];
  string name<255>;
};
```

  - Types can be passed across the network
- **Standard `rpcgen` compiles to C**
  - Converts messages to native data structures
  - Generates marshaling routines (struct $\leftrightarrow$ byte stream)
  - Generates info for stub routines

Basic data types

- `int var` – **32-bit signed integer**
  - wire rep: big endian (0x11223344 → 0x11, 0x22, 0x33, 0x44)
  - rpcgen rep: `int32_t var`
- `hyper var` – **64-bit signed integer**
  - wire rep: big endian
  - rpcgen rep: `int64_t var`
- `unsigned int var`, `unsigned hyper var`
  - wire rep: same as signed
  - rpcgen rep: `u_int32_t var`, `u_int64_t var`

More basic types

- `void` – **No data**
  - wire rep: 0 bytes of data
- `enum {name = constant,...}` – **enumeration**
  - wire rep: Same as `int`
  - rpcgen rep: `enum`
- `bool var` – **boolean**
  - both reps: As if `enum bool {FALSE = 0, TRUE = 1} var`

Opaque data

- `opaque var[n]` – **`n` bytes of opaque data**
  - wire rep: `n` bytes of data, 0-padded to multiple of 4
    `opaque v[5]` $\rightarrow$ `v[0]`, `v[1]`, `v[2]`, `v[3]`, `v[4]`, 0, 0, 0
  - rpcgen rep: `char var[n]`

Variable length opaque data

- `opaque var<n>` **– 0–`n` bytes of opaque data**
  - wire rep: 4-byte data size in big endian format, followed by `n` bytes of data, 0-padded to multiple of 4
  - rpcgen rep:

```
typedef struct {
  u_int32_t var_len;
  char *var_val;
} var;
```

- `opaque var<>` **– arbitrary length opaque data**
  - wire rep: same
  - rpcgen rep: same

Strings

- **`string var<n>` – string of up to `n` bytes**
  - wire rep: just like `opaque var<n>`
  - rpcgen rep: `char *var;`
    except cannot be NULL, cannot be longer than `n` bytes
- **`string var<>` – arbitrary length string**
  - wire rep: same as `string var<n>`
  - rpcgen rep: same
- **Note: Strings cannot contain 0-valued bytes**
  - Should be allowed by RFC
  - Because of C string implementations, does not work

Arrays

- `obj_t var[n]` – **Array of** `n` `obj_t`**s**
  - wire rep: `n` wire reps of `obj_t` in a row
  - rpcgen rep: `typedef obj_t var[20];`
- `obj_t var<n>` – **0–**`n` `obj_t`**s**
  - wire rep: array size in big endian, followed by that many wire reps of `obj_t`
  - rpcgen rep:

```
typedef struct {
  u_int32_t var_len;
  obj_t *var_val;
} var;
```

Pointers

- `obj_t *var` – **"optional"** `obj_t`
  - wire rep: same as `obj_t var<1>`: Either just 0, or 1 followed by wire rep of `obj_t`
  - rpcgen rep: `obj_t *var`
- **Pointers allow linked lists:**

```
struct entry {
  filename name;
  entry *nextentry;
};
```

- **Not to be confused with network object pointers!**

Structures

```
struct type {
  type_A fieldA;
  type_B fieldB;
  ...
};
```

- **wire rep: wire representation of each field in order**
- **rpcgen rep: structure as defined**

Discriminated unions

```
union type switch (simple_type which) {
  case value_A:
    type_A varA;
  case value_B:
    type_B varB;
  ...
  default:
    void;
};
```

- `simple_type` **must be** `[unsigned] int`**,** `bool`**, or** `enum`
- **Wire representation: wire rep of** `which`**, followed by wire rep of case selected by** `which`**.**

Discriminated unions: rpcgen representation

```
struct type {
  simple_type which;
  union {
    type_A varA;
    type_B varB;
    ...
  } type_u;
};
```

- **Must check/set `which` before accessing field**
- **Warning: Accessing the wrong field is a common bug, and causes unpredictable behavior**

RPC message format

```
enum msg_type { CALL = 0, REPLY = 1 };
struct rpc_msg {
   unsigned int xid;
   union switch (msg_type mtype) {
   case CALL:
      call_body cbody;
   case REPLY:
      reply_body rbody;
   } body;
};
```

- **32-bit XID identifies each RPC**
  - Chosen by client, returned by server
  - Server may base replay cache on XID

RPC call format

```
struct call_body {
   unsigned int rpcvers;  /* must always be 2 */
   unsigned int prog;
   unsigned int vers;
   unsigned int proc;
   opaque_auth  cred;
   opaque_auth  verf;
   /* argument structure goes here */
};
```

- **Every call has a 32-bit program & version number**
  - E.g., NFS is program 100003, versions 2 & 3 in use
  - Can implement multiple servers on same port
- **Opaque auth is hook for authentication & security**
  - Credentials – who you are; Verifier – proof.

RPC reply format

```
enum reply_stat { MSG_ACCEPTED = 0, MSG_DENIED = 1 };
union reply_body switch (reply_stat stat) {
case MSG_ACCEPTED:
   accepted_reply areply;
case MSG_DENIED:
   rejected_reply rreply;
} reply;
```

- **Most calls generate “accepted replies”**
  - Includes many error conditions, too
- **Authentication failures produce “rejected replies”**

Accepted calls

```
struct accepted_reply {
    opaque_auth verf;
    union switch (accept_stat stat) {
    case SUCCESS:
       /* result structure goes here */
     case PROG_MISMATCH:
       struct { unsigned low; unsigned high; }
          mismatch_info;
     default:
     /* PROG/PROC_UNAVAIL, GARBAGE_ARGS, SYSTEM_ERR, ... */
        void;
     } reply_data;
 };
```

Rejected calls

```
enum reject_stat { RPC_MISMATCH = 0, AUTH_ERROR = 1 }
union rejected_reply switch (reject_stat stat) {
case RPC_MISMATCH:
   struct {
      unsigned int low;
      unsigned int high;
   } mismatch_info;     /* means rpcvers != 2 */
case AUTH_ERROR:
   auth_stat stat;      /* Authentication insufficient */
};
```

RPC authentication

```
enum auth_flavor {
   AUTH_NONE = 0,
   AUTH_SYS = 1,   /* a.k.a. AUTH_UNIX */
   AUTH_SHORT = 2,
   AUTH_DES = 3
};
struct opaque_auth {
   auth_flavor flavor;
   opaque body<400>;
};
```

- **Opaque allows new types w/o changing RPC lib**
  - E.g., SFS adds AUTH_UINT=10, containing simple integer

AUTH_UNIX credential flavors

```
struct authsys_parms {
   unsigned int time;
   string machinename<255>;
   unsigned int uid;
   unsigned int gid;
   unsigned int gids<16>;
};
```

- **Contains credentials of user on client machine**
- **Only useful if:**
  1. Server trusts client machine, and
  2. Client and server have same UIDs/GIDs, and
  3. Network between client and server is secure

Example: fetch and add server

```
struct fadd_arg {
  string var<>;
  int inc;
};

union fadd_res switch (bool error) {
case TRUE:
  int sum;
case FALSE:
  string msg<>;
};
```

RPC program definition

```
program FADD_PROG {
  version FADD_VERS {
    void FADDPROC_NULL (void) = 0;
    fadd_res FADDPROC_FADD (fadd_arg) = 1;
  } = 1;
} = 300001;
```

- **RPC library needs information for each call**
  - prog, vers, marshaling function for arg and result
- **rpcgen encapsulates all needed info in a struct**
  - Lower-case prog name, numeric version: `fadd_prog_1`