

## Part III: Extending ns

1

## Outline

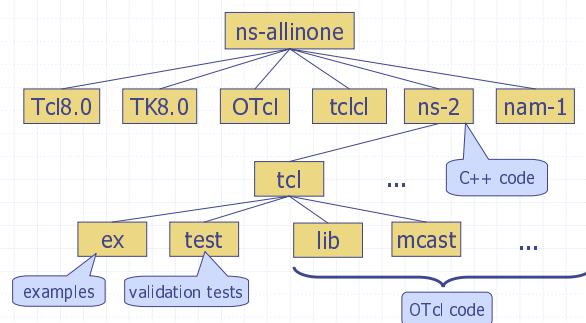
- ◆ Extending ns
  - In OTcl
  - In C++
- ◆ Debugging

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## ns Directory Structure



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## Extending ns in OTcl

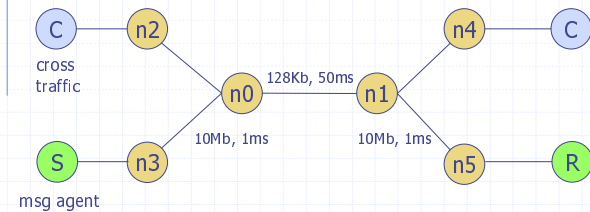
- ◆ If you don't want to compile
  - `source` your changes in your sim scripts
- ◆ Otherwise
  - Modifying code; recompile
  - Adding new files
    - ◆ Change Makefile (NS\_TCL\_LIB), `tcl/lib/ns-lib.tcl`
    - ◆ Recompile

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## Example: Agent/Message



## Agent/Message



- ◆ A UDP agent (without UDP header)
- ◆ Up to 64 bytes user message
- ◆ Good for fast prototyping a simple idea
- ◆ Usage requires extending ns functionality

## Agent/Message: Step 1

### ◆ Define sender

```
class Sender -superclass Agent/Message

# Message format: "Addr Op SeqNo"
Sender instproc send-next {} {
    $self instvar seq_ agent_addr_
    $self send "$agent_addr_ send $seq_"
    incr seq_
    global ns
    $ns at [expr [$ns now]+0.1] "$self send-next"
}
```

## Agent/Message: Step 2

### ◆ Define sender packet processing

```
Sender instproc recv msg {
    $self instvar agent_addr_
    set sdr [lindex $msg 0]
    set seq [lindex $msg 2]
    puts "Sender gets ack $seq from $sdr"
}
```

## Agent/Message: Step 3

### ◆ Define receiver packet processing

```
Class Receiver -superclass Agent/Message
Receiver instproc recv msg {
  $self instvar agent_addr_
  set sdr [lindex $msg 0]
  set seq [lindex $msg 2]
  puts "Receiver gets seq $seq from $sdr"
  $self send "$addr_ ack $seq"
}
```

## Agent/Message: Step 4

### ◆ Scheduler and tracing

```
# Create scheduler
set ns [new Simulator]

# Turn on Tracing
set fd [new "message.nam" w]
$ns namtrace-all $fd
```

## Agent/Message: Step 5

### ◆ Topology

```
for {set i 0} {$i < 6} {incr i} {
  set n($i) [$ns node]
}
$ns duplex-link $n(0) $n(1) 128kb 50ms DropTail
$ns duplex-link $n(1) $n(4) 10Mb 1ms DropTail
$ns duplex-link $n(1) $n(5) 10Mb 1ms DropTail
$ns duplex-link $n(0) $n(2) 10Mb 1ms DropTail
$ns duplex-link $n(0) $n(3) 10Mb 1ms DropTail

$ns queue-limit $n(0) $n(1) 5
$ns queue-limit $n(1) $n(0) 5
```

## Agent/Message: Step 6

### ◆ Routing

```
# Packet loss produced by queuing

# Routing protocol: let's run distance vector
$ns rtproto DV
```

## Agent/Message: Step 7

### ◆ Cross traffic

```
set udp0 [new Agent/UDP]
$ns attach-agent $n(2) $udp0
set null0 [new Agent/NULL]
$ns attach-agent $n(4) $null0
$ns connect $udp0 $null0

set exp0 [new Application/Traffic/Exponential]
$exp0 set rate_ 128k
$exp0 attach-agent $udp0
$ns at 1.0 "$exp0 start"
```

## Agent/Message: Step 8

### ◆ Message agents

```
set sdr [new Sender]
$sdr set packetSize_ 1000

set rcvr [new Receiver]
$rcvr set packetSize_ 40

$ns attach $n(3) $sdr
$ns attach $n(5) $rcvr
$ns connect $sdr $rcvr
$ns connect $rcvr $sdr
$ns at 1.1 "$sdr send-next"
```

## Agent/Message: Step 9

### ◆ End-of-simulation wrapper (as usual)

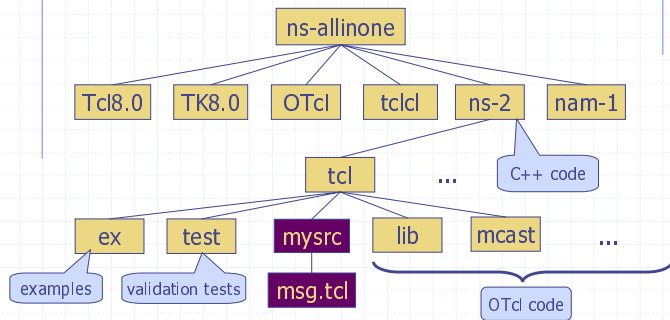
```
$ns at 2.0 finish
proc finish {} {
    global ns fd
    $ns flush-trace
    close $fd
    exit 0
}
```

## Agent/Message: Result

### ◆ Example output

```
> ./ns msg.tcl
Receiver gets seq 0 from 0
Sender gets ack 0 from 1
Receiver gets seq 1 from 0
Sender gets ack 1 from 1
Receiver gets seq 2 from 0
Sender gets ack 2 from 1
Receiver gets seq 3 from 0
Sender gets ack 3 from 1
Receiver gets seq 4 from 0
Sender gets ack 4 from 1
Receiver gets seq 5 from 0
```

## Add Your Changes into ns



## Add Your Change into ns

- ◆ tcl/lib/ns-lib.tcl  
Class Simulator  
...  
source ../mysrc/msg.tcl
- ◆ Makefile  
NS\_TCL\_LIB = \  
tcl/mysrc/msg.tcl \  
...  
  - Or: change Makefile.in, make distclean, then  
./configure --enable-debug

## Outline

- ◆ Extending ns
  - In OTcl
  - In C++
    - ◆ New components

## Extending ns in C++

- ◆ Modifying code
  - make depend
  - Recompile
- ◆ Adding code in new files
  - Change Makefile
  - make depend
  - recompile

## Creating New Components

- ◆ Guidelines
- ◆ Two styles
  - New agent based on existing packet headers
  - Add new packet header

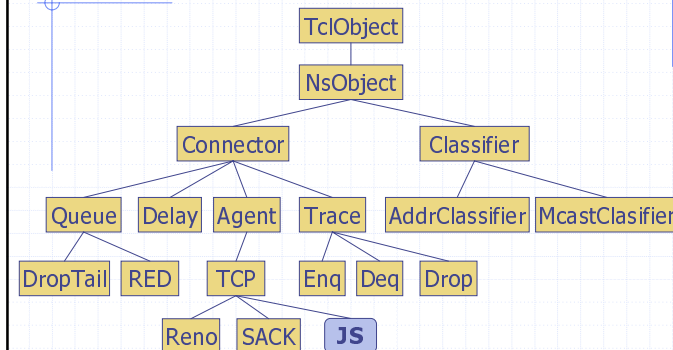
## Guidelines

- ◆ Decide position in class hierarchy
  - I.e., which class to derive from?
- ◆ Create new packet header (if necessary)
- ◆ Create C++ class, fill in methods
- ◆ Define OTcl linkage (if any)
- ◆ Write OTcl code (if any)
- ◆ Build (and debug)

## New Agent, Old Header

- ◆ TCP jump start
  - Wide-open transmission window at the beginning
  - From  $cwnd_+ = 1$  TO  $cwnd_ = MAXWIN_$

## TCP Jump Start – Step 1



## TCP Jump Start – Step 2

### ◆ New file: tcp-js.h

```
class JSTCPAgent : public TcpAgent {
public:
    virtual void set_initial_window() {
        cwnd_ = MAXWIN_;
    }
private:
    int MAXWIN_;
};
```

## TCP Jump Start – Step 3

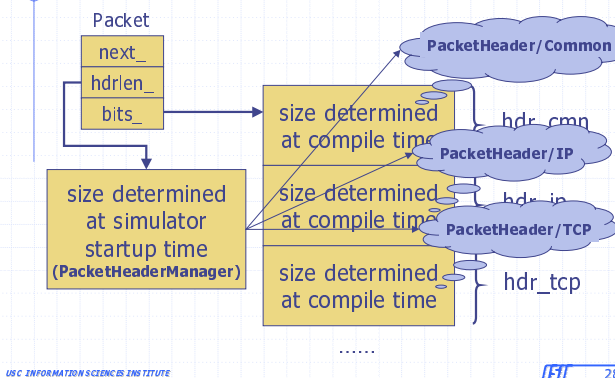
### ◆ New file: tcp-js.cc

```
static JSTcpClass : public TclClass {
public:
    JSTcpClass() : TclClass("Agent/TCP/JS") {}
    TclObject* create(int, const char*const*) {
        return (new JSTcpAgent());
    }
};
JSTcpAgent::JSTcpAgent() {
    bind("MAXWIN_", MAXWIN_);
}
```

## New Packet Header

- ◆ Create new header structure
- ◆ Enable tracing support of new header
- ◆ Create static class for OTcl linkage (packet.h)
- ◆ Enable new header in OTcl (tcl/lib/ns-packet.tcl)
- ◆ This does not apply when you add a new field into an existing header!

## How Packet Header Works



## Example: Agent/Message

- ◆ New packet header for 64-byte message
- ◆ New transport agent to process this new header

## New Packet Header – Step 1

- ◆ Create header structure

```
struct hdr_msg {
    char msg_[64];
    static int offset_;
    inline static int& offset() { return offset_; }
    inline static hdr_msg* access(Packet* p) {
        return (hdr_msg*) p->access(offset_);
    }
    /* per-field member functions */
    char* msg() { return (msg_); }
    int maxmsg() { return (sizeof(msg_)); }
};
```

## New Packet Header – Step 2

- ◆ PacketHeader/Message

```
static class MessageHeaderClass :
    public PacketHeaderClass {
public:
    MessageHeaderClass() :
        PacketHeaderClass("PacketHeader/Message",
                          sizeof(hdr_msg)) {
        bind_offset(&hdr_msg::offset_);
    }
} class_msghdr;
```

## New Packet Header – Step 3

- ◆ Enable tracing (packet.h):

```
enum packet_t {
    PT_TCP,
    ...,
    PT_MESSAGE,
    PT_NTTYPE // This MUST be the LAST one
};
class p_info {
    .....
    name_[PT_MESSAGE] = "message";
    name_[PT_NTTYPE]= "undefined";
    .....
};
```



## New Packet Header – Step 4

- ◆ Register new header (tcl/lib/ns-packet.tcl)

```
foreach pair {  
  { Common off_cmn_  
  ...  
  { Message off_msg_  
}
```

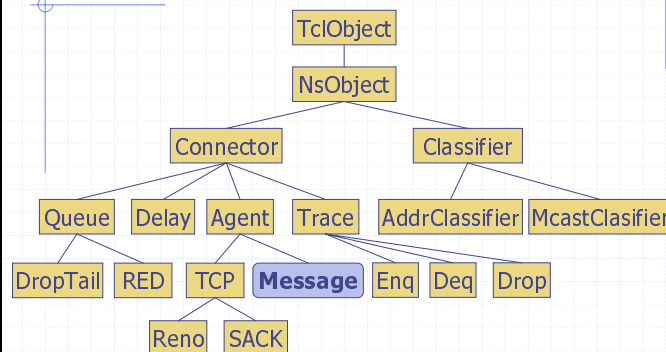
## Packet Header: Caution

- ◆ Some old code, e.g.:

```
RtpAgent::RtpAgent() {  
  .....  
  bind("off_rtp_", &off_rtp);  
}  
.....  
hdr_rtp* rh = (hdr_rtp*)p->access(off_rtp_);
```

- ◆ **Don't follow this example!**

## Agent/Message – Step 1



## Agent/Message – Step 2

- ◆ C++ class definition

```
// Standard split object declaration  
static ...  
  
class MessageAgent : public Agent {  
public:  
  MessageAgent() : Agent(PT_MESSAGE) {}  
  virtual int command(int argc, const char*const*  
  argv);  
  virtual void recv(Packet*, Handler*);  
};
```

## Agent/Message – Step 3

### ◆ Packet processing: send

```
int MessageAgent::command(int, const char*const* argv)
{
    Tcl& tcl = Tcl::instance();
    if (strcmp(argv[1], "send") == 0) {
        Packet* pkt = allocpkt();
        hdr_msg* mh = hdr_msg::access(pkt);
        // We ignore message size check...
        strcpy(mh->msg(), argv[2]);
        send(pkt, 0);
        return (TCL_OK);
    }
    return (Agent::command(argc, argv));
}
```

## Agent/Message – Step 4

### ◆ Packet processing: receive

```
void MessageAgent::recv(Packet* pkt, Handler*)
{
    hdr_msg* mh = hdr_msg::access(pkt);

    // OTcl callback
    char wrk[128];
    sprintf(wrk, "%s recv {%s}", name(), mh->msg());
    Tcl& tcl = Tcl::instance();
    tcl.eval(wrk);

    Packet::free(pkt);
}
```

## Outline

### ◆ Extending ns

- In OTcl
- In C++
- Debugging: OTcl/C++, memory
- Pitfalls

## Debugging C++ in ns

### ◆ C++/OTcl debugging

### ◆ Memory debugging

- purify
- dmalloc

## C++/OTcl Debugging

- ◆ Usual technique
  - Break inside command()
  - Cannot examine states inside OTcl!
- ◆ Solution
  - Execute tcl-debug inside gdb

## C++/OTcl Debugging

```
(gdb) call Tcl::instance().eval("debug 1")
15: lappend auto_path $dbg_library
dbg15.3> w
*0: application
  15: lappend auto_path $dbg_library
dbg15.4> Simulator info instances
_o1
dbg15.5> _o1 now
0
dbg15.6> # and other fun stuff
dbg15.7> c
(gdb) where
#0 0x102218 in write()
.....
```

## Memory Debugging in ns

- ◆ Purify
  - Set PURIFY macro in ns Makefile
  - Usually, put -collector=<ld\_path>
- ◆ Gray Watson's dmalloc library
  - <http://www.dmalloc.com>
  - make distclean
  - ./configure --with-dmalloc=<dmalloc\_path>
  - Analyze results: dmalloc\_summarize

## dmalloc: Usage

- ◆ Turn on dmalloc
  - alias dmalloc 'eval `dmalloc -C \!\*`'
  - dmalloc -l log low
- ◆ dmalloc\_summarize ns < logfile
  - ns must be in current directory
  - Itemize how much memory is allocated in each function

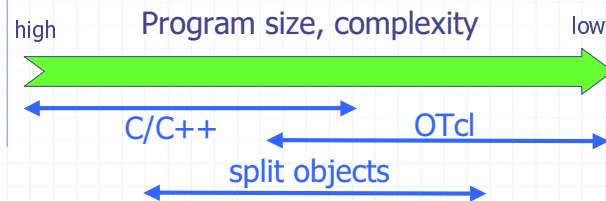
## Pitfalls

- ◆ Scalability vs flexibility
  - Or, how to write scalable simulation?
- ◆ Memory conservation tips
- ◆ Memory leaks

## Scalability vs Flexibility

- ◆ It's tempting to write all-OTcl simulation
  - Benefit: quick prototyping
  - Cost: memory + runtime
- ◆ Solution
  - Control the granularity of your split object by migrating methods from OTcl to C++

## THE Merit of OTcl



- ◆ Smoothly adjust the granularity of scripting to balance extensibility and performance
- ◆ With complete compatibility with existing simulation scripts

## Object Granularity Tips

- ◆ Functionality
  - Per-packet processing → C++
  - Hooks, frequently changing code → OTcl
- ◆ Data management
  - Complex/large data structure → C++
  - One-time configuration variables → OTcl

## Memory Conservation Tips

- ◆ Avoid `trace-all`
- ◆ Use arrays for a sequence of variables
  - Instead of `n$i`, say `n($i)`
- ◆ Avoid OTcl temporary variables
- ◆ Use dynamic binding
  - `delay_bind()` instead of `bind()`
  - See `object.{h,cc}`

## Memory Leaks

- ◆ Purify or `dmalloc`, but be careful about split objects:

```
for {set i 0} {$i < 500} {incr i} {
    set a [new RandomVariable/Constant]
}
```

  - It leaks memory, but can't be detected!
- ◆ Solution
  - Explicitly delete EVERY split object that was new-ed

## Final Word

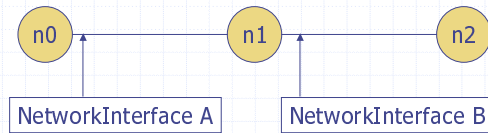
- ◆ My extended `ns` dumps OTcl scripts!
  - Find the last 10-20 lines of the dump
  - Is the error related to "`_o*** cmd ...`"?
    - ◆ Check your `command()`
  - Otherwise, check the otcl script pointed by the error message

## Case Studies

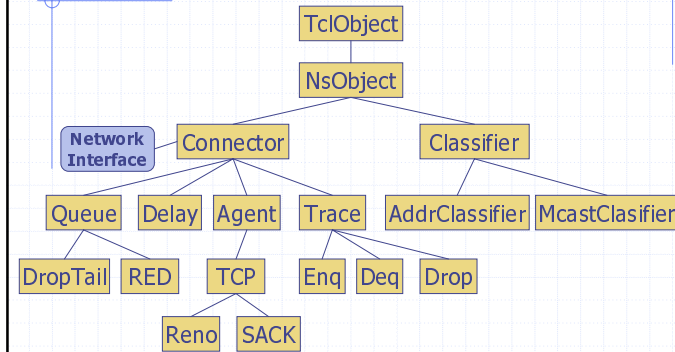
- ◆ Network Layer: Network Interface (packet labeler)
- ◆ Transport Layer: TCP Jump Start
- ◆ Application Layer: Message agent (ping)

## Case 1: Network Layer

- ◆ Network interface: packet labeler



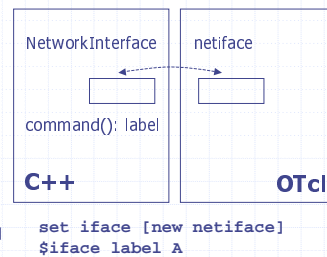
## ns Class Hierarchy (Partial)



## Network Interface Labeler

```

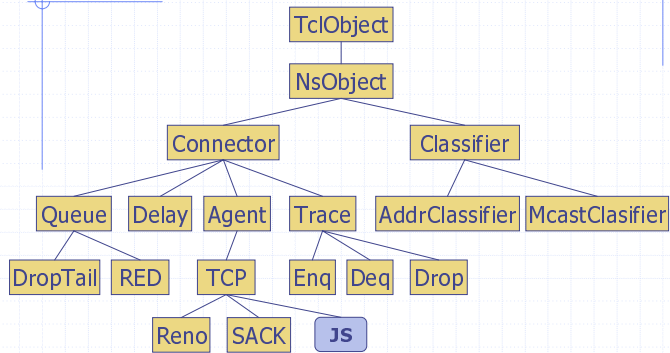
class NetworkInterface
  NetworkInterface()
  recv(pkt)
  pkt->iface()=label
  send(pkt)
  target->recv(pkt)
  command(argc, argv)
  label:
    label_ = argv[1]
  TclClass("netiface")
  
```



## Case 2: Transport Layer

- ◆ TCP jump start
  - From cwnd += 1
  - to cwnd = MAXWIN

## ns Class Hierarchy (Partial)



## TCP Jump Start

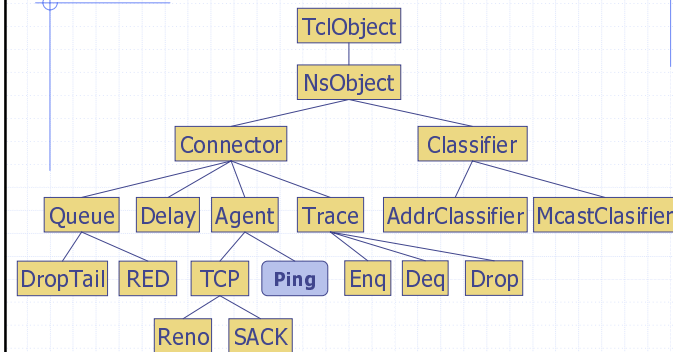
- ◆ Class JSTCPAgent
  - openwin()
  - slowdown()
- ◆ TclClass("Agent/TCP/JS")

## Case 3: Application Layer

- ◆ Message sender (ping)

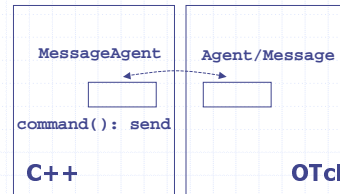


## ns Class Hierarchy (Partial)



## Message Sender

```
class MessageAgent
MessageAgent()
recv()
send()
command()
send {send()}
```



```
TclClass("Agent/Message")
```

```
set msg [new Agent/Message]
$msg send
```

## Agent/Message/Talk?

- ◆ What if we want to build a **reliable** message agent?
- ◆ Two choices
  - Add a message field to TCP header, and modify a TCP agent to handle this field
  - Application-level data

## Application-Level Data

- ◆ New packet header
  - Unnecessarily occupies space
  - Difficult to build on top of transport protocols
- ◆ Application-level data
  - Only allocated for simulations that use them
  - Easy to interface with transport protocols
  - Generic, extensible data representation AppData
  - Use `packet::data_`