15-744: Computer Networking

The network simulator ns-2

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Slides loosely based on tutorials by Polly Huang (ETH), John Heidemann (USC/ICSI) and Bianca (CMU).

What is ns?

- **N**etwork **s**imulator
- a *discrete event simulator*
- focused on *modeling network protocols*
  - wired, wireless, satellite
  - TCP, UDP, multicast, unicast
  - Web, telnet, ftp
  - Ad hoc routing; sensor networks
  - Infrastructure: stats, tracing, error models etc.

ns -- goals

- Allow collaboration
  - Freely distributed, open source
  - Results can be verified
  - Protocols can be compared
- Support *networking research* and *education*

ns --- what is it good for?

Used to:

- **Evaluate** performance of existing network **protocols**.
- Prototyping and evaluation of **new protocols**.
- **Large-scale** simulations not possible in real experiments.

ns

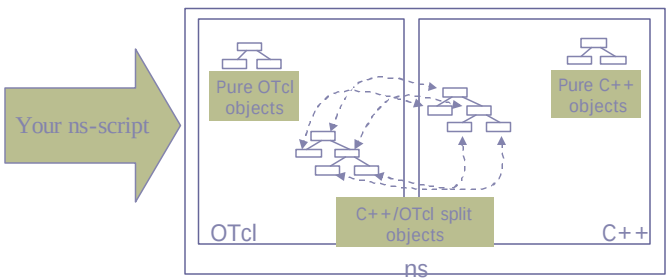
How does it work:

- **Event-driven** simulator
  - Model world as *events*
  - Simulator has list of events
  - Process: take next one, run it, until done
  - Each event happens in instant of *virtual* time, but takes arbitrary *real* time
- Single thread of control
- Packet level

ns - software structure

- Object oriented (C++, OTcl) – code reuse
- Scalability + Extensibility
  - Control/"data" separation
  - Split C++/OTcl object
- C++ for packet-processing (fast to run)
- OTcl for control - (fast to write)
  - Simulation setup and configuration

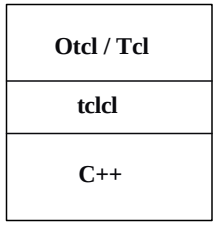
otcl and C++: The Duality



Development Status

Current status:

- 100K lines of **C++ code**
- 70K lines of **otcl code**
- 20K lines of **documentation**
- User base about 1K institutions, 10K users.



Outline

- Overview
- **Tcl, OTcl basics**
- ns basics
- Extending ns
- ns internals

Tcl basics

```
proc fact {x} {
    set ret 1
    if {$x > 2} {
        for {set i 1} {$i <= $x} {incr i} {
            set ret [expr $i * $ret]
        }
    }
    puts "factorial of $x is $ret"
}
```

fact 5 → factorial of 5 is 120

Tcl basics

```
proc fact {x} {
    set ret 1
    if {$x > 2} {
        for {set i 1} {$i <= $x} {incr i} {
            set ret [expr $i * $ret]
        }
    }
    puts "factorial of $x is $ret"
}
```

fact 5 → factorial of 5 is 120

- $ for de-referencing
- Spaces - important
- {} defines a block
- set, puts
- proc definition: proc name args body

Basic otcl

```
Class mom

mom instproc init {age} {
    $self instvar age_
    set age_ $age
}

mom instproc greet {} {
    $self instvar age_
    puts "$age_ years old mom: How are you doing?"
}
```

```
set a [new mom 45]
$a greet
```

- instead of single class declaration **multiple definitions**
- **instproc** adds class methods
- **instvar** adds instance variable, and brings them to the local scope
- **$self** : **this** in Java, C++
- all methods **virtual** (as in Java)

Basic otcl - inheritance

```
Class kid -superclass mom

kid instproc greet {} {
    $self instvar age_
    puts "$age_ years old kid:
    What's up, dude?"
}
```

```
set b [new kid 15]
$b greet
```

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Basic structure of ns-scripts

- Creating the event scheduler
- [Tracing]
- Creating network topology
- Creating Transport Layer - **Agents**
- Creating Applications - **Applications**
- Events!

Creating Event Scheduler

- **Create scheduler**
  - set ns [new Simulator]
- **Schedule event**
  - $ns at <time> <event>
  - <event>: any legitimate ns/tcl commands
- **Start scheduler**
  - $ns run

"Hello World" in ns

simple.tcl

```
set ns [new Simulator]
$ns at 1 "puts \"Hello World!\""
$ns at 1.5 "exit"
$ns run
```

```
bovik@gs19% ns simple.tcl
Hello World!
bovik@gs19%
```

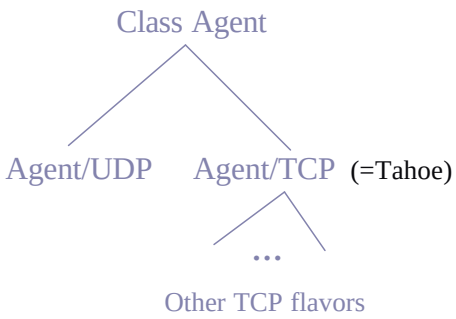
Creating Network

- Nodes
  - set n0 [$ns node]
  - set n1 [$ns node]
- Links & Queuing
  - $ns duplex-link $n0 $n1 <bandwidth> <delay> <queue_type>
  - Queue type: DropTail, RED, CBQ, FQ, SFQ, DRR

Routing + traffic

- Unicast
  - $ns rtproto <type>
  - <type>: Static, Session, DV
- Multicast support also.
- Traffic
  - Simple two layers: transport and application.
  - Transport: TCP, UDP etc.
  - Applications: web, ftp, telnet etc.

Transport Layer



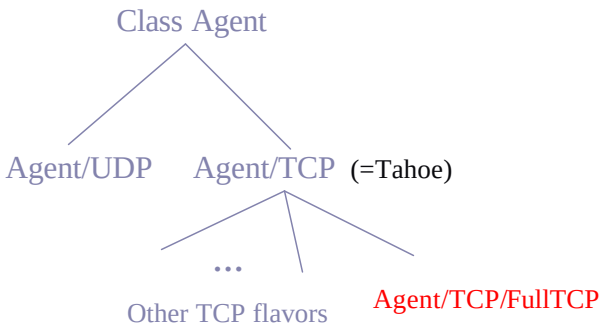
The transport layer: UDP

- UDP
  - set udp [new Agent/UDP]
  - set null [new Agent/NULL]
  - $ns attach-agent $n0 $udp
  - $ns attach-agent $n1 $null
  - $ns connect $udp $null

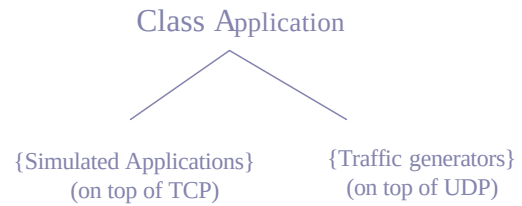
The transport layer: TCP

- TCP
  - set tcp [new Agent/TCP]
  - set tcpsink [new Agent/TCPSink]
  - $ns attach-agent $n0 $tcp
  - $ns attach-agent $n1 $tcpsink
  - $ns connect $tcp $tcpsink

Transport Layer



Application Layer



Creating Traffic: On Top of TCP

FTP

- set ftp [new **Application/FTP**]
- $ftp attach-agent $tcp
- $ns at <time> “$ftp start”

Telnet

- set telnet [new **Application/Telnet**]
- $telnet attach-agent $tcp

Creating Traffic: On Top of UDP

- CBR
  - set src [new **Application/Traffic/CBR**]
- Exponential or Pareto on-off
  - set src [new **Application/Traffic/Exponential**]
  - set src [new **Application/Traffic/Pareto**]
- Trace driven traffic
  - Inter-packet time and packet-size

Attaching a traffic source

- set cbr [new Application/Traffic/CBR]
- $cbr attach-agent $udp
- $ns at <time> “$cbr start”

Tracing

Trace packets on all links:

- set f[open out.tr w]
- $ns trace-all $f

- $ns flush-trace
- close $f

```
<event><time><from><to><type><size>--<flags>--<flow id><src><dst><seqno> <pckt id>
     + 1 0 2 cbr 210 ------- 0 0.0 3.1 0 0
     - 1 0 2 cbr 210 ------- 0 0.0 3.1 0 0
     r 1.00234 0 2 cbr 210 ------- 0 0.0 3.1 0 0
```

Is tracing **all** links always the best thing to do?

More Tracing

- Tracing **specific links**
  - $ns trace-queue $n0 $n1 $f
- Tracing **variables**
  - set cwnd_chan_ [open all.cwnd w]
  - $tcp trace cwnd_
  - $tcp attach $cwnd_chan_

Controlling object parameters

- Almost all ns objects have *parameters*
  - ex. Application/Traffic/Exponential has *rate* and *packetSize*
  - *set* parameters in OTcl
    - set etraf [new Application/Traffic/Exponential]
    - $etraf set rate_ 1Mb
    - $etraf set packetSize_ 1024

Putting it all together

```
set ns [new Simulator]
set n0 [$ns node]
set n1 [$ns node]
$ns duplex-link $n0 $n1 1.5Mb
    10ms DropTail
$ns trace-queue $n0 $n1 $f
set tcp [$ns create-connection TCP
    $n0 TCPSink $n1 0]
set ftp [new Application/FTP]
$ftp attach-agent $tcp
$ns at 0.2 "$ftp start"
$ns at 1.2 "exit"
$ns run
```

Creating **Topology**

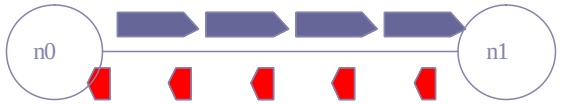
Creating **Transport layer**

Creating **Applications**

Schedule **Events**

nam – the network animator

```
set nf [open out.nam w]
$ns namtrace-all $nf
   …
exec nam out.nam &
```



ns “components”

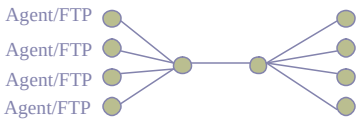
- **ns,** the simulator itself
- **nam**, the Network AniMator
  - Visualize ns output
  - GUI input simple ns scenarios
- Pre-processing:
  - Traffic and topology generators
- Post-processing:
  - Simple trace analysis, often in Awk, Perl, or Tcl

Network Dynamics: Link failures

- $ns rtmodel-at <time> <up|down> $n0 $n1
- $ns rtmodel Trace <config_file> $n0 $n1
- $ns rtmodel <model> <params> $n0 $n1
  <model>: Deterministic, Exponential

Issues in Simulations

- Suppose you want to study the way TCP sources share a bottleneck link…



Which topology?

Which traffic sources?

Background Traffic?

When to start sources?

What else affects results?

Another practical issue: Memory

~ns/tcl/ex/cmcast-150.tcl:

150 nodes, 2200 links => 53MB
2420 nodes, 2465 links => 800MB

- Avoid `trace-all`
- Use arrays for a sequence of variables
  - Instead of `n$i`, say `n($i)`

Basic ns-2: Not Covered

- mobile IP
- multicasting
- satellite
- emulation

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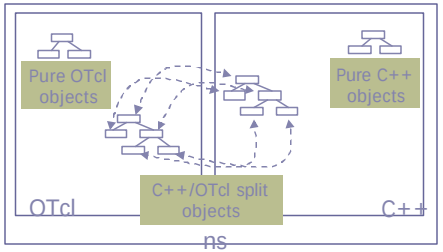
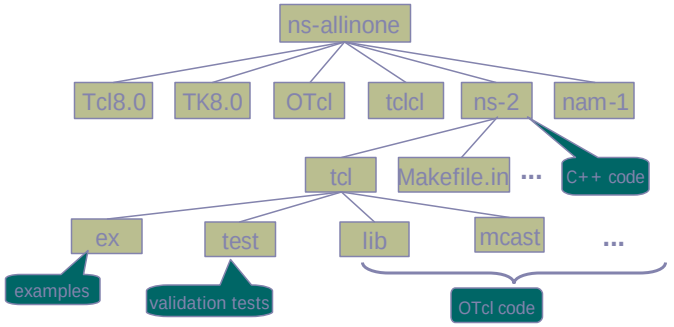
Making changes to ns – where???



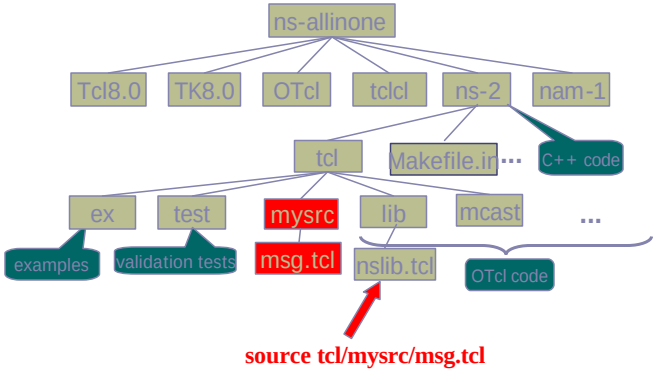
Where would you implement

- one-time configuration variables
- complex procedures
- per packet action

ns directory structure



New component purely in Otcl



New component in C++

- Create **C++ class**, fill in methods
- Define **otcl linkage**
- Write **otcl code** (if any)
- Build (and debug)

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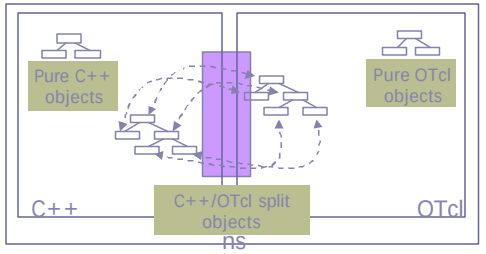
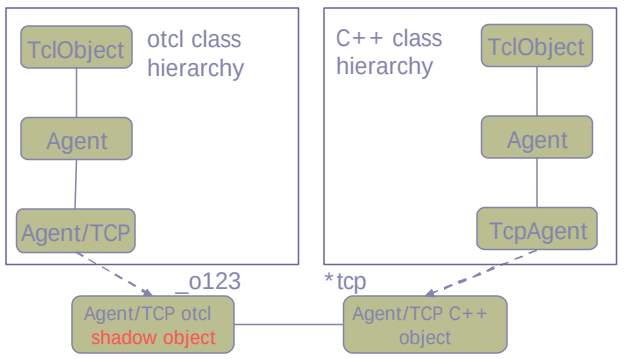
How does linkage work?



- how to access Tcl variables from C++
- how is C++ object created from interpreter
- ……

TclObject: Hierarchy and Shadowing



TclObject

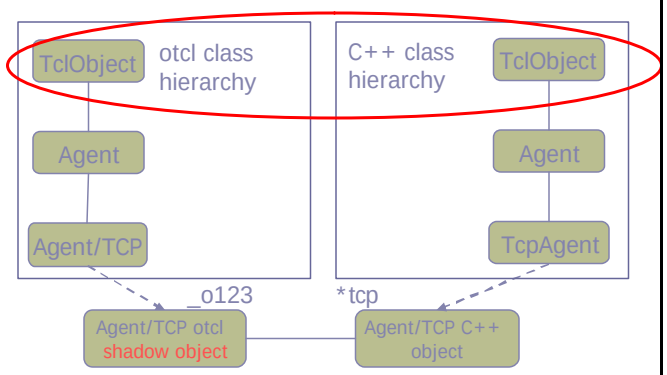
- Example

```
set tcp [new Agent/TCP]
```
=> how is corresponding C++ object created?

```
$tcp set window_ 500
```
=> how is corresponding C++ variable set?

```
$tcp advance 5000
```
=> how is C++ procedure called?

TclObject: Hierarchy and Shadowing



TclObject::bind()

- Link C++ member variables to otcl object variables
- C++

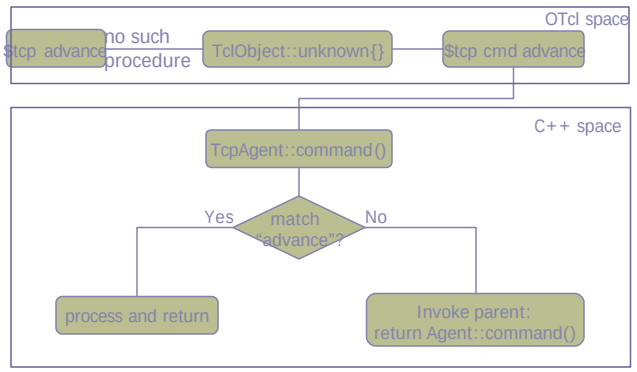
```
TcpAgent::TcpAgent() {
    bind("window_", &wnd_);
    … …
}
```
  - bind_time(), bind_bool(), bind_bw()
- otcl

```
$tcp set window_ 200
```

TclObject::command()

- Implement otcl methods in C++
- Trap point: otcl method cmd{}
- Send all arguments after cmd{} call to TclObject::command()

TclObject::command()



TclObject::command()

- otcl

```
set tcp [new Agent/TCP]
$tcp advance 10
```

- C++

```
int TcpAgent::command(int argc,
                      const char*const* argv) {
    if (argc == 3) {
        if (strcmp(argv[1], "advance") == 0) {
            int newseq = atoi(argv[2]);
            ……
            return(TCL_OK);
        }
    }
    return (Agent::command(argc, argv);
}
```

TclObject

- Example

`set tcp [new Agent/TCP]` ?

=> how is corresponding C++ object created?

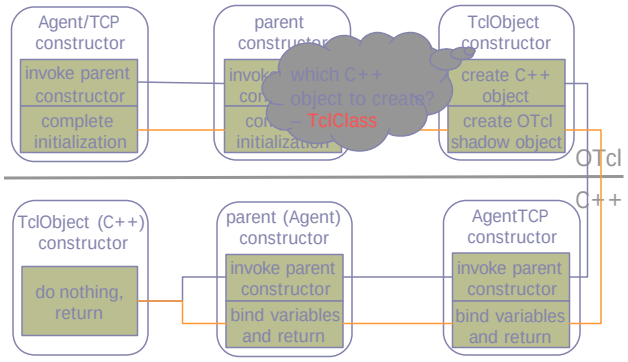
`$tcp set window_ 500` ✓

=> how is corresponding C++ variable set?

`$tcp advance 5000` ✓

=> how is C++ procedure called?

TclObject: Creation and Deletion



TclClass

```
Static class TcpClass : public TclClass {
public:
    TcpClass() : TclClass("Agent/TCP") {}
    TclObject* create(int, const char*const*) {
        return (new TcpAgent());
    }
} class_tcp;
```

Class Tcl

- Singleton class with a handle to Tcl interpreter
  - While writing C++ code
- Usage
  - Invoke otcl procedure
  - Obtain otcl evaluation results
  - Pass a result string to otcl
  - Return success/failure code to otcl

Class Tcl

```
Tcl& tcl = Tcl::instance();
```

Passing results to the interpreter:

```
if (strcmp(argv[1], "now") == 0) {
        tcl.resultf("%g", clock());
        return TCL_OK;
}
```

Executing Otcl commands from C++

```
if (strcmp(argv[1], "helloworld") {
    tcl.evalc("puts stdout Hello World");
    return TCL_OK;
}
```

Class TclCommand

- C++ implementation of global otcl commands

```
class RandomCommand : public TclCommand {
public:
        RandomCommand() : TclCommand("ns-random") {}
        virtual int command(int argc, const char*const* argv);
};

int RandomCommand::command(int argc, const char*const* argv)
{
        Tcl& tcl = Tcl::instance();
        if (argc == 1) {
                sprintf(tcl.buffer(), "%u", Random::random());
                tcl.result(tcl.buffer());
        }
```

Summary

TclObject	Root of ns-2 object hierarchy
	bind(): link variable values between C++ and OTcl
	command(): link OTcl methods to C++ implementations
TclClass	Create and initialize TclObject's
Tcl	C++ methods to access Tcl interpreter
TclCommand	Standalone global commands
EmbeddedTcl	ns script initialization