Ns Tutorial 2002

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Nov 21, 2002

Introduction

- 1989: REAL network simulator
- 1995: DARPA VINT project at LBL, Xerox PARC, UCB, and USC/ISI
- Present: DARPA SAMAN project and NSF CONSER project
  - Collaboration with other researchers including CIRI

Ns Goals

- Support networking research and education
  - Protocol design, traffic studies, etc
  - Protocol comparison
- Provide a *collaborative* environment
  - Freely distributed, *open source*
    - Share code, protocols, models, etc
  - Allow easy *comparison* of similar protocols
  - *Increase confidence* in results
    - More people look at models in more situations
    - Experts develop models
- *Multiple levels of detail* in one simulator

SAMAN and CONSER Projects

- SAMAN: build robust networks through understanding the detection and prediction of failure conditions
  - ASIM, RAMP, and NEWS
- CONSER: extending ns and nam to support:
  - Network research:
    - New module integration: diffserv, direct diffusion
    - Existing module improvement, new trace, etc
  - Network education: nam and nam editor, educational scripts repository, ns-edu mailing list, ns tutorial, etc

Ns Status

- Periodical release (ns-2.1b9a, July 2002)
  - ~200K LOC in C++ and Otcl,
  - ~100 test suites and 100+ examples
  - 371 pages of ns manual
  - Daily snapshot (with auto-validation)
- Stability validation
  - http://www.isi.edu/nsnam/ns/ns-tests.html
- Platform support
  - FreeBSD, Linux, Solaris, Windows and Mac
- User base
  - > 1k institutes (50 countries), >10k users
  - About 300 posts to ns-users@isi.edu every month

Ns functionalities

- Wired world
  - Routing DV, LS, PIM-SM
  - Transportation: TCP and UDP
  - Traffic sources:web, ftp, telnet, cbr, stochastic
  - Queuing disciplines:drop-tail, RED, FQ, SFQ, DRR
  - QoS: IntServ and Diffserv
  - Emulation
- Wireless
  - Ad hoc routing and mobile IP
  - Directed diffusion, sensor-MAC
- Tracing, visualization, various utilities

“Ns” Components

- Ns, the simulator itself
- Nam, the network animator
  - Visualize *ns* (or other) output
  - Nam editor: GUI interface to generate ns scripts
- Pre-processing:
  - Traffic and topology generators
- Post-processing:
  - Simple trace analysis, often in Awk, Perl, or Tcl

Ns Models

- Traffic models and applications:
  - Web, FTP, telnet, constant-bit rate, real audio
- Transport protocols:
  - unicast: TCP (Reno, Vegas, etc.), UDP
  - Multicast: SRM
- Routing and queueing:
  - Wired routing, ad hoc rtg and directed diffusion
  - queueing protocols: RED, drop-tail, etc
- Physical media:
  - Wired (point-to-point, LANs), wireless (multiple propagation models), satellite

Installation

- Getting the pieces
  - Tcl/TK 8.x (8.3.2 preferred): http://resource.tcl.tk/resource/software/tcltk/
  - Otcl and TclCL: http://otcl-tclcl.sourceforge.net
  - ns-2 and nam-1: http://www.isi.edu/nsnam/dist
- Other utilities
  - http://www.isi.edu/nsnam/ns/ns-build.html
  - Tcl-debug, GT-ITM, xgraph, …

Help and Resources

- Ns and nam build questions
  - http://www.isi.edu/nsnam/ns/ns-build.html
- Ns mailing list: ns-users@isi.edu
- Ns manual and tutorial (in distribution)
- TCL: http://dev.scriptics.com/scripting
- Otcl tutorial (in distribution): ftp://ftp.tns.lcs.mit.edu/pub/otcl/doc/tutorial.html

Cautions

- We tried best to validate *ns* with regression tests
- However: abstraction of the real world is necessary for a simulator
- You must justify the usage of this simulator based on your research goals

Tutorial Schedule

- First session (Nov 21, 2002)
  - Introduction
  - Ns fundamentals
  - Extending ns
  - Lab
- Second session (Nov 22, 2002)
  - Diffserv model (including lab)
  - Wireless networks (including lab)

Part I: ns fundamentals

Ns-2, the Network Simulator

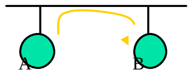
- A *discrete event simulator*
  - Simple model
- Focused on *modeling network protocols*
  - Wired, wireless, satellite
  - TCP, UDP, multicast, unicast
  - Web, telnet, ftp
  - Ad hoc routing, sensor networks
  - Infrastructure: stats, tracing, error models, etc

Discrete Event Simulation

- Model world as *events*
  - Simulator has list of events
  - Process: take next one, run it, until done
  - Each event happens in an instant of *virtual (simulated) time*, but takes an arbitrary amount of *real* time
- Ns uses simple model: single thread of control => no locking or race conditions to worry about (very easy)

Discrete Event Examples

Consider two nodes on an Ethernet:



simple queuing model:

t=1, A enqueues pkt on LAN
t=1.01, LAN dequeues pkt and triggers B

detailed CSMA/CD model:

t=1.0: A sends pkt to NIC
A's NIC starts carrier sense
t=1.005: A's NIC concludes cs, starts tx
t=1.006: B's NIC begins reciving pkt
t=1.01: B's NIC concludes pkt
B's NIC passes pkt to app

Ns Architecture

- Object-oriented (C++, OTcl)
- Modular approach
  - Fine-grained object composition

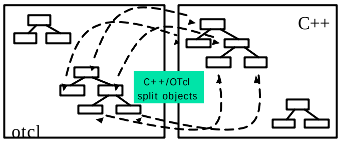
+ Reusability
+ Maintenance
– Performance (speed and memory)
– Careful planning of modularity

C++ and OTcl Separation

- "data" / control separation
  - C++ for "data":
    - per packet processing, core of *ns*
    - fast to run, detailed, complete control
  - OTcl for control:
    - Simulation scenario configurations
    - Periodic or triggered action
    - Manipulating existing C++ objects
    - fast to write and change

+ running vs. writing speed
– Learning and debugging (two languages)

Otcl and C++: The Duality



- OTcl (object variant of Tcl) and C++ share class hierarchy
- TclCL is glue library that makes it easy to share functions, variables, etc

Basic Tcl

variables:

```
set x 10
puts "x is $x"
```

functions and expressions:

```
set y [pow x 2]
set y [expr x*x]
```

control flow:

```
if {$x > 0} { return $x } else {
    return [expr -$x] }
while { $x > 0 } {
    puts $x
    incr x –1
}
```

procedures:

```
proc pow {x n} {
    if {$n == 1} { return $x }
    set part [pow x [expr $n-1]]
    return [expr $x*$part]
}
```

Also lists, associative arrays, etc.

=> can use a real programming language to build network topologies, traffic models, etc.

Basic otcl

```
Class Person
# constructor:
Person instproc init {age} {
    $self instvar age_
    set age_ $age
}
# method:
Person instproc greet {} {
    $self instvar age_
    puts "$age_ years old: How
    are you doing?"
}
```

```
# subclass:
Class Kid -superclass Person
Kid instproc greet {} {
    $self instvar age_
    puts "$age_ years old kid:
    What's up, dude?"
}

set a [new Person 45]
set b [new Kid 15]
$a greet
$b greet
```

=> can easily make variations of existing things (TCP, TCP/Reno)

C++ and OTcl Linkage

- Class Tcl: instance of OTcl interpreter

  Tcl& tcl = Tcl::instance();

  tcl.evalc("puts stdout hello world");

  tcl.result() and tcl.error
- Class TclObject and TclClass
  - Variable bindings

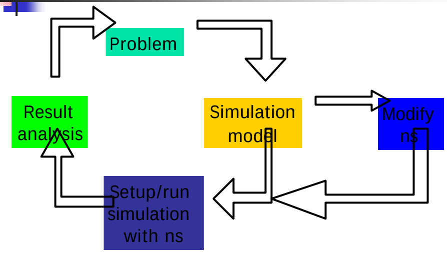
  bind("rtt_", &t_rtt_)
  - Invoking command method in shadow class

  $tcp advanceby 10

C++ and Otcl linkage II

- Some important objects:
  - NsObject: has recv() method
  - Connector: has target() and drop()
  - BiConnector: uptarget() & downtarget()

Using *ns*



Ns programming

- Create the event scheduler
- Turn on tracing
- Create network
- Setup routing
- Insert errors
- Create transport connection
- Create traffic
- Transmit application-level data

Creating Event Scheduler

- Create event scheduler

  set ns [new Simulator]
- Schedule events

  $ns at <time> <event>
  - <event>: any legitimate ns/tcl commands

  $ns at 5.0 “finish”
- Start scheduler

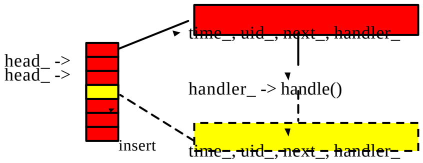
  $ns run

Event Scheduler

- Event: at-event and packet
- List scheduler: default
  - Heap and calendar queue scheduler
- Real-time scheduler
  - Synchronize with real-time
  - Network emulation

```
set ns_ [new Simulator]
$ns_ use-scheduler Heap
$ns_ at 300.5 “$self halt”
```

Discrete Event Scheduler



Hello World - Interactive Mode

Interactive mode:

```
swallow 71% ns
% set ns [new Simulator]
_o3
% $ns at 1 “puts \“Hello
   World!\””
1
% $ns at 1.5 “exit”
2
% $ns run
Hello World!
swallow 72%
```

Batch mode:

```
simple.tcl
    set ns [new Simulator]
    $ns at 1 “puts \“Hello
       World!\””
    $ns at 1.5 “exit”
    $ns run
swallow 74% ns
   simple.tcl
Hello World!
swallow 75%
```

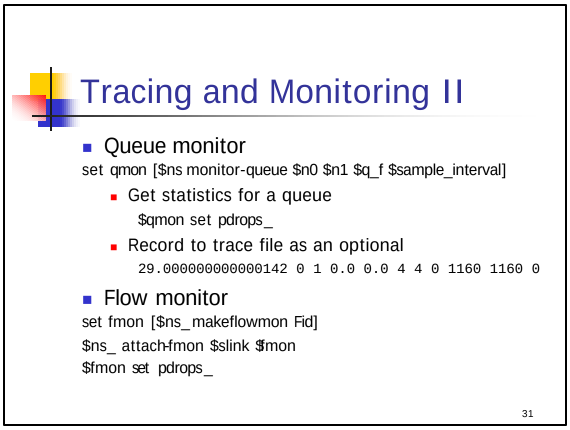
Tracing and Monitoring I

- Packet tracing:
  - On all links: $ns trace-all [open out.tr w]
  - On one specific link: $ns trace-queue $n0 $n1$tr

```
<Event> <time> <from> <to> <pkt> <size> -- <fid> <src> <dst> <seq> <attr>
   + 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
```

  - We have new trace format
- Event tracing (support TCP right now)
  - Record “event” in trace file: $ns eventtrace-all

```
E 2.267203 0 4 TCP slow_start 0 210 1
```



Tracing and Monitoring II

- Queue monitor

```
set qmon [$ns monitor-queue $n0 $n1 $q_f $sample_interval]
```

  - Get statistics for a queue

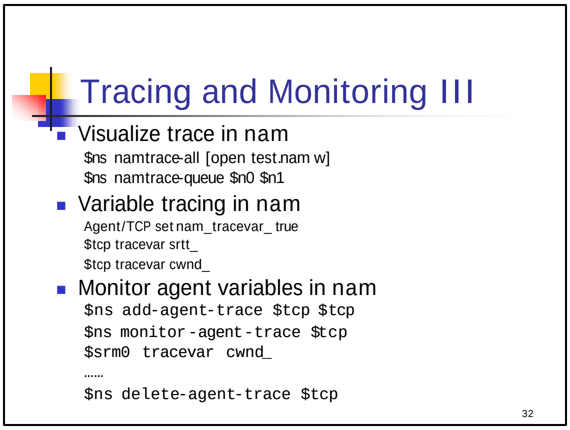
```
$qmon set pdrops_
```

  - Record to trace file as an optional

```
29.000000000000142 0 1 0.0 0.0 4 4 0 1160 1160 0
```

- Flow monitor

```
set fmon [$ns_ makeflowmon Fid]
$ns_ attach-fmon $slink $fmon
$fmon set pdrops_
```



Tracing and Monitoring III

- Visualize trace in nam

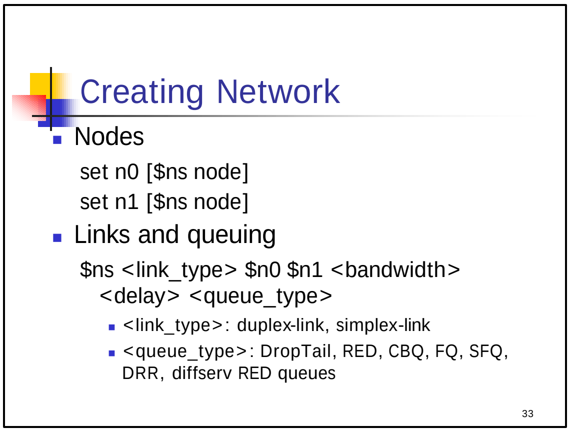
```
$ns namtrace-all [open test.nam w]
$ns namtrace-queue $n0 $n1
```

- Variable tracing in nam

```
Agent/TCP set nam_tracevar_ true
$tcp tracevar srtt_
$tcp tracevar cwnd_
```

- Monitor agent variables in nam

```
$ns add-agent-trace $tcp $tcp
$ns monitor-agent-trace $tcp
$srm0 tracevar cwnd_
……
$ns delete-agent-trace $tcp
```



Creating Network

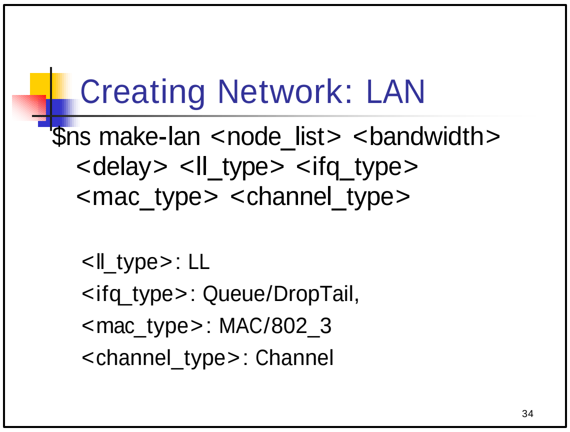
- Nodes

```
set n0 [$ns node]
set n1 [$ns node]
```

- Links and queuing

```
$ns <link_type> $n0 $n1 <bandwidth>
   <delay> <queue_type>
```

  - <link_type>: duplex-link, simplex-link
  - <queue_type>: DropTail, RED, CBQ, FQ, SFQ, DRR, diffserv RED queues



Creating Network: LAN

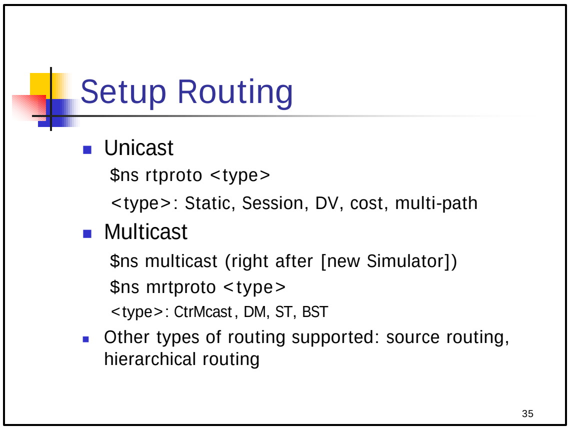
```
$ns make-lan <node_list> <bandwidth>
   <delay> <ll_type> <ifq_type>
   <mac_type> <channel_type>
```

<ll_type>: LL

<ifq_type>: Queue/DropTail,

<mac_type>: MAC/802_3

<channel_type>: Channel



Setup Routing

- Unicast

```
$ns rtproto <type>
```

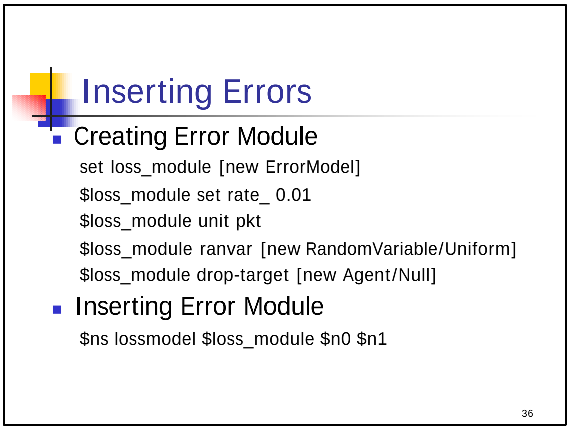
<type>: Static, Session, DV, cost, multi-path

- Multicast

```
$ns multicast (right after [new Simulator])
$ns mrtproto <type>
```

<type>: CtrMcast, DM, ST, BST

- Other types of routing supported: source routing, hierarchical routing



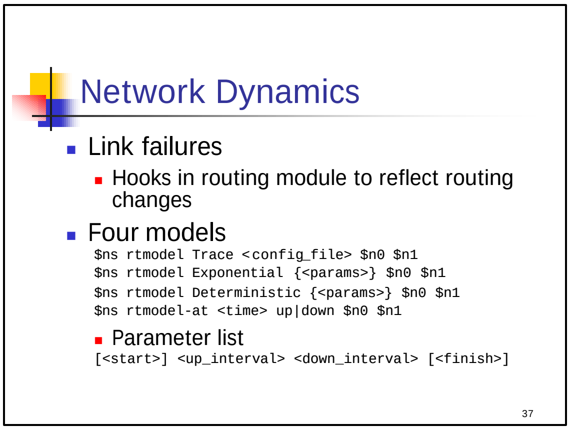
Inserting Errors

- Creating Error Module

```
set loss_module [new ErrorModel]
$loss_module set rate_ 0.01
$loss_module unit pkt
$loss_module ranvar [new RandomVariable/Uniform]
$loss_module drop-target [new Agent/Null]
```

- Inserting Error Module

```
$ns lossmodel $loss_module $n0 $n1
```



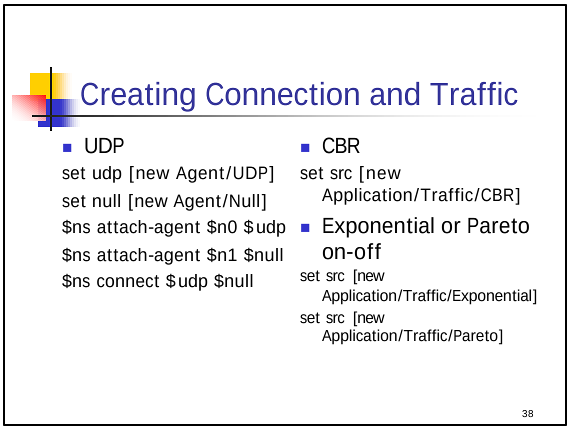
Network Dynamics

- Link failures
  - Hooks in routing module to reflect routing changes
- Four models

```
$ns rtmodel Trace <config_file> $n0 $n1
$ns rtmodel Exponential {<params>} $n0 $n1
$ns rtmodel Deterministic {<params>} $n0 $n1
$ns rtmodel-at <time> up|down $n0 $n1
```

  - Parameter list

```
[<start>] <up_interval> <down_interval> [<finish>]
```



Creating Connection and Traffic

- UDP

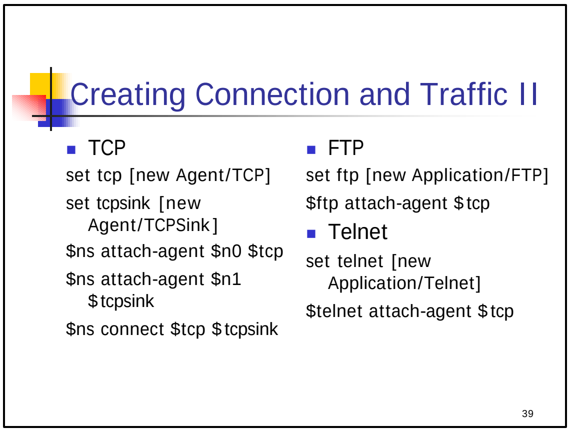
```
set udp [new Agent/UDP]
set null [new Agent/Null]
$ns attach-agent $n0 $udp
$ns attach-agent $n1 $null
$ns connect $udp $null
```

- CBR

```
set src [new
   Application/Traffic/CBR]
```

- Exponential or Pareto on-off

```
set src [new
   Application/Traffic/Exponential]
set src [new
   Application/Traffic/Pareto]
```



Creating Connection and Traffic II

- TCP

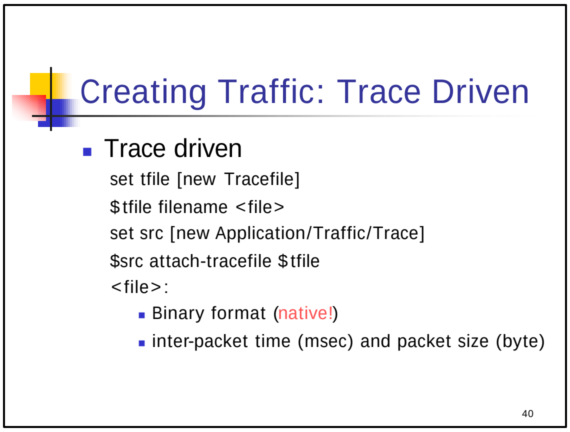
```
set tcp [new Agent/TCP]
set tcpsink [new
   Agent/TCPSink]
$ns attach-agent $n0 $tcp
$ns attach-agent $n1
   $tcpsink
$ns connect $tcp $tcpsink
```

- FTP

```
set ftp [new Application/FTP]
$ftp attach-agent $tcp
```

- Telnet

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

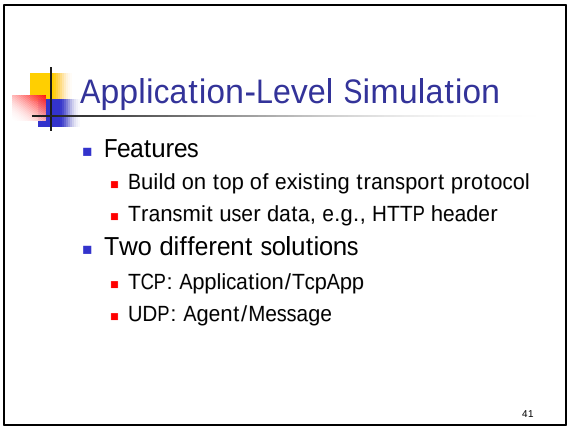


Creating Traffic: Trace Driven

- Trace driven

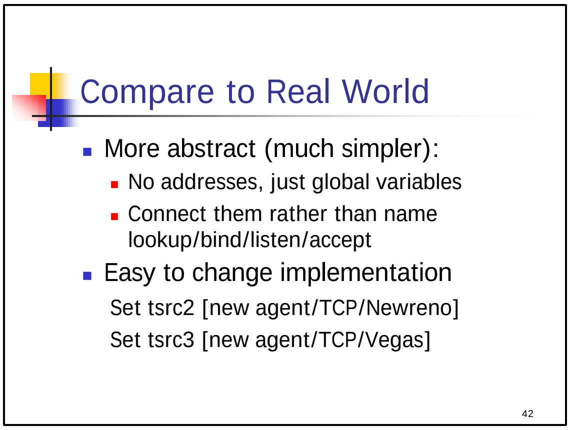
```
set tfile [new Tracefile]
$tfile filename <file>
set src [new Application/Traffic/Trace]
$src attach-tracefile $tfile
```

  <file>:
  - Binary format (native!)
  - inter-packet time (msec) and packet size (byte)



Application-Level Simulation

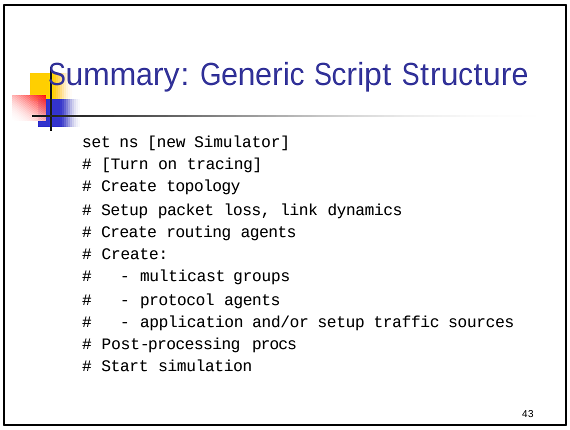
- Features
  - Build on top of existing transport protocol
  - Transmit user data, e.g., HTTP header
- Two different solutions
  - TCP: Application/TcpApp
  - UDP: Agent/Message



Compare to Real World

- More abstract (much simpler):
  - No addresses, just global variables
  - Connect them rather than name lookup/bind/listen/accept
- Easy to change implementation

```
Set tsrc2 [new agent/TCP/Newreno]
Set tsrc3 [new agent/TCP/Vegas]
```



Summary: Generic Script Structure

```
set ns [new Simulator]
# [Turn on tracing]
# Create topology
# Setup packet loss, link dynamics
# Create routing agents
# Create:
#   - multicast groups
#   - protocol agents
#   - application and/or setup traffic sources
# Post-processing procs
# Start simulation
```

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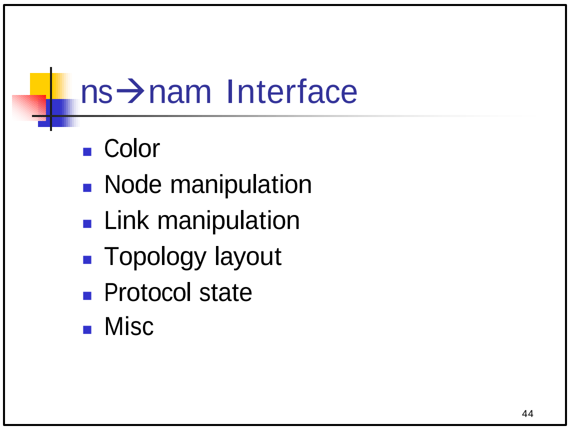

ns→nam Interface

- Color
- Node manipulation
- Link manipulation
- Topology layout
- Protocol state
- Misc

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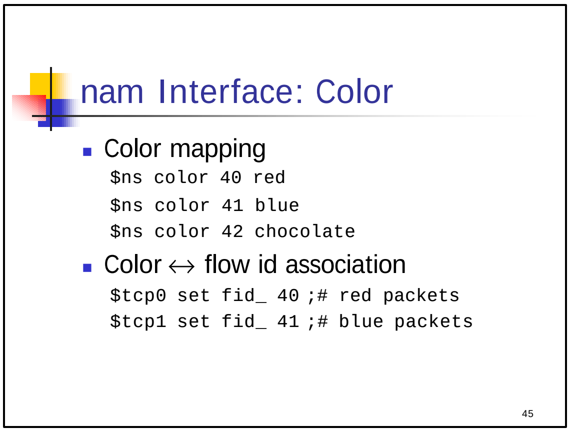

nam Interface: Color

- Color mapping

```
$ns color 40 red
$ns color 41 blue
$ns color 42 chocolate
```

- Color ↔ flow id association

```
$tcp0 set fid_ 40 ;# red packets
$tcp1 set fid_ 41 ;# blue packets
```

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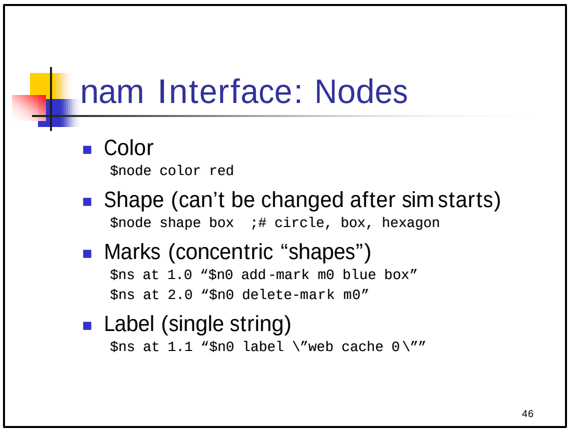

nam Interface: Nodes

- Color

```
$node color red
```

- Shape (can’t be changed after sim starts)

```
$node shape box  ;# circle, box, hexagon
```

- Marks (concentric “shapes”)

```
$ns at 1.0 “$n0 add-mark m0 blue box”
$ns at 2.0 “$n0 delete-mark m0”
```

- Label (single string)

```
$ns at 1.1 “$n0 label \”web cache 0\””
```

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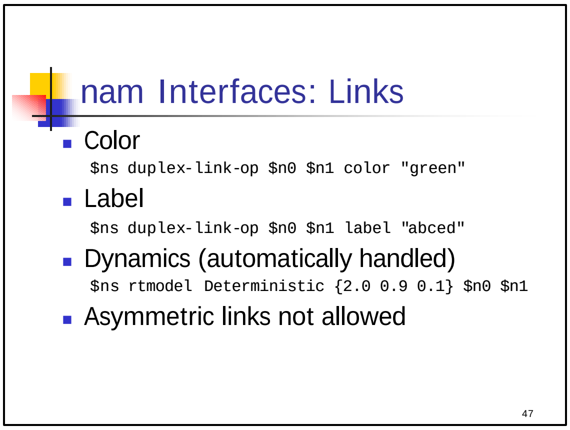

nam Interfaces: Links

- Color

```
$ns duplex-link-op $n0 $n1 color "green"
```

- Label

```
$ns duplex-link-op $n0 $n1 label "abced"
```

- Dynamics (automatically handled)

```
$ns rtmodel Deterministic {2.0 0.9 0.1} $n0 $n1
```

- Asymmetric links not allowed

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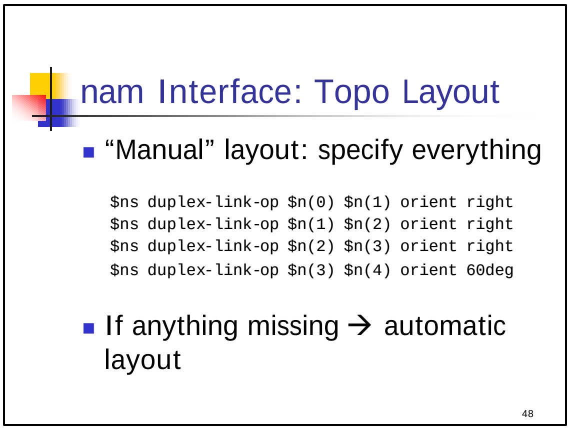

nam Interface: Topo Layout

- “Manual” layout: specify everything

```
$ns duplex-link-op $n(0) $n(1) orient right
$ns duplex-link-op $n(1) $n(2) orient right
$ns duplex-link-op $n(2) $n(3) orient right
$ns duplex-link-op $n(3) $n(4) orient 60deg
```

- If anything missing → automatic layout

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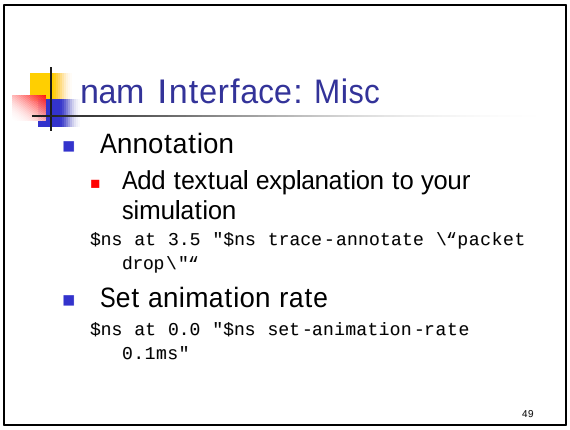


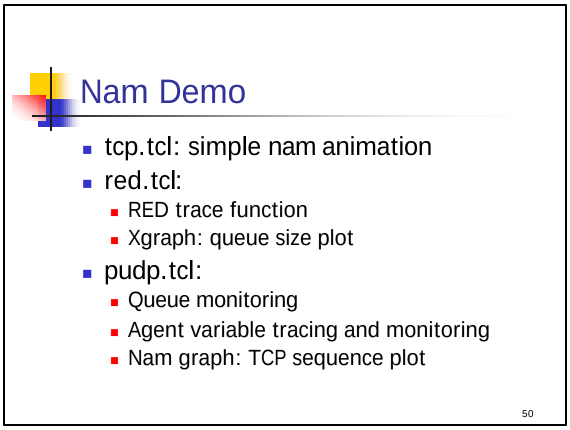
nam Interface: Misc

- Annotation
  - Add textual explanation to your simulation

```
$ns at 3.5 "$ns trace-annotate \“packet
   drop\"“
```

- Set animation rate

```
$ns at 0.0 "$ns set-animation-rate
   0.1ms"
```



Nam Demo

- tcp.tcl: simple nam animation
- red.tcl:
  - RED trace function
  - Xgraph: queue size plot
- pudp.tcl:
  - Queue monitoring
  - Agent variable tracing and monitoring
  - Nam graph: TCP sequence plot