ns-3 training

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ns-3 annual meeting 2019

June 17-21, Florence, Italy

UNIVERSITY *of* WASHINGTON

Next steps

- Code organization and build system
- Documentation system
- Packet objects and queues
- Walkthrough of ‘mm1-queue.cc’ example
  - Simple experiment management
  - Objects, attributes, tracing
  - Logging and debugging

Software orientation

Key differences from other network simulators:

1) Command-line, Unix orientation

- vs. Integrated Development Environment (IDE)

2) Simulations and models written directly in C++ and Python

- vs. a domain-specific simulation language

ns-3 not written in a high-level language

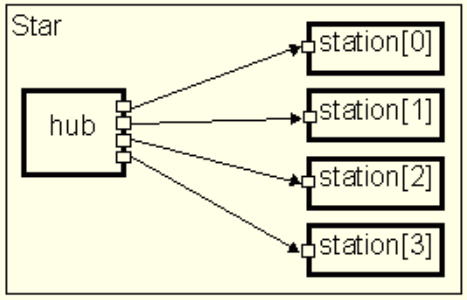
Submodule vectors, gate vectors and multiple connections are illustrated in the following example:

```
simple Hub
  gates:
    out: outport[];
endsimple

simple Station //...

module Star
  submodules:
    hub: Hub
      gatesizes: outport[4];
    station: Station[4];
  connections:
    for i=0..3 do
          hub.outport[i] --> station[i].in;
    endfor
endmodule
```

The result of the above is depicted in Fig.4.



Example of OMNeT++ Network Description (NED) language
Figure excerpted from http://www.ewh.ieee.org/soc/es/Nov1999/18/ned.htm

ns-3 does not have a graphical IDE

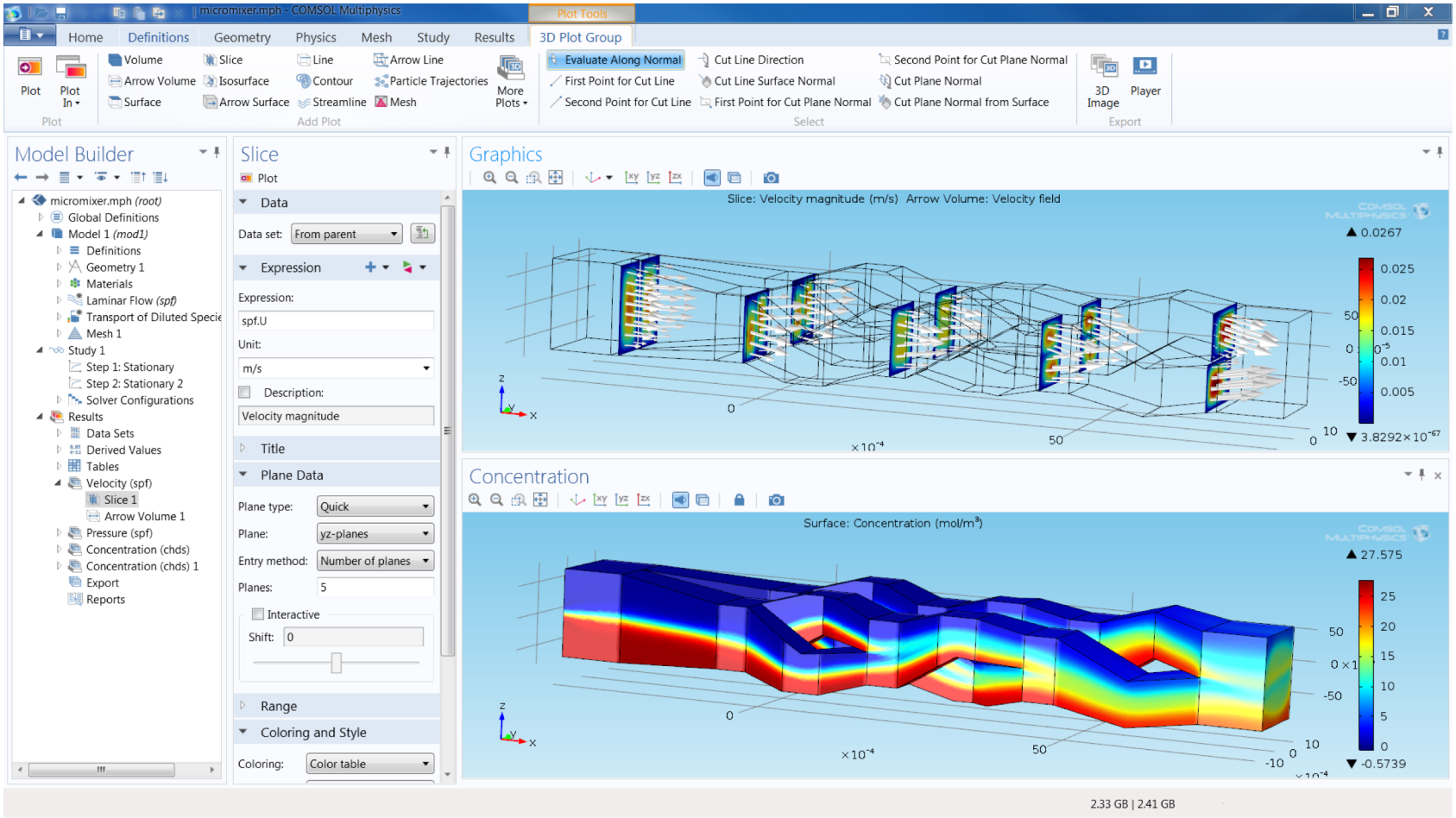
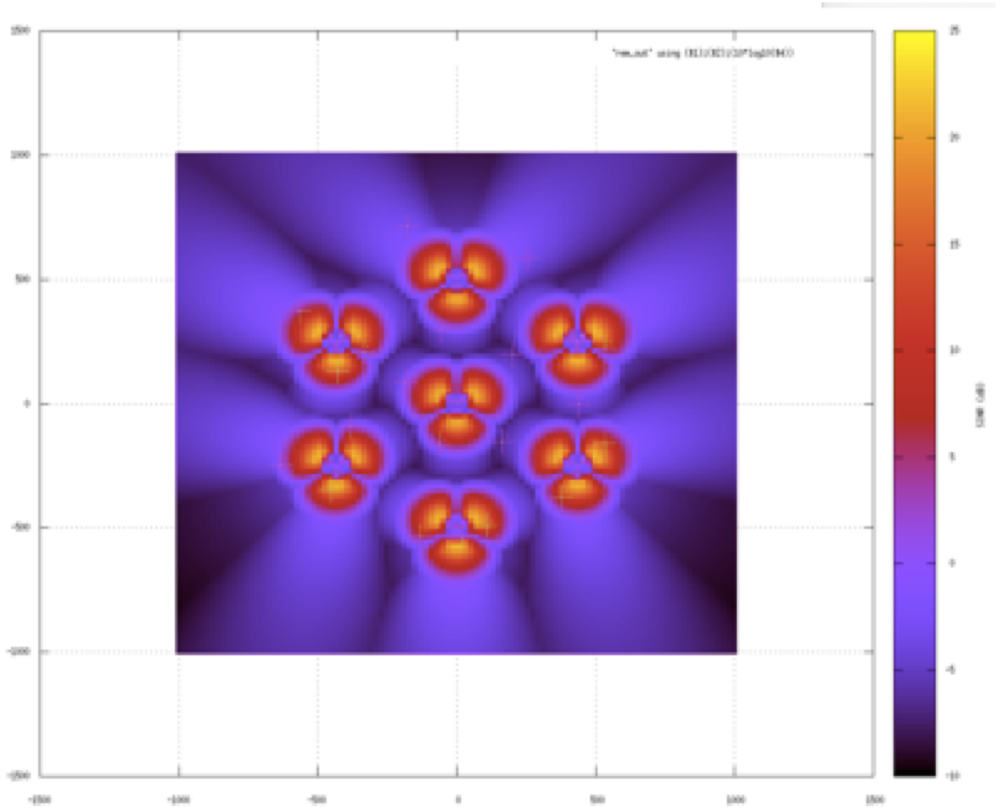


Figure source: https://www.comsol.com/comsol-multiphysics

ns-3 uses outside programs for graphics



gnuplot

LTE radio environment map (REM)

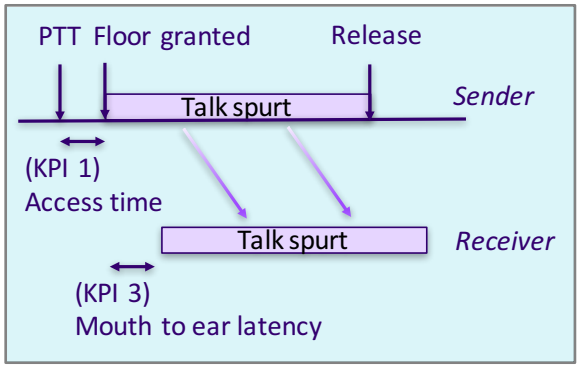
Will experiment with this on Tuesday

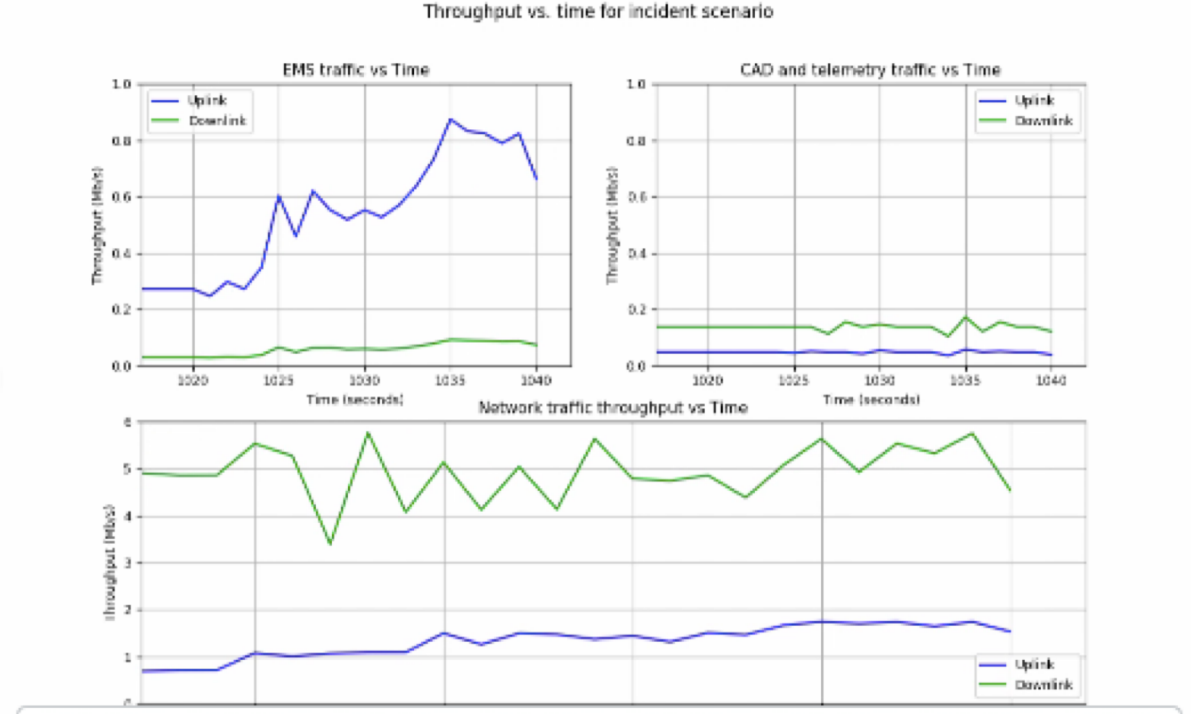
ns-3 users typically write scripts to plot

Animated

EmsVideo_1_Server 942.36392953 RX 1012 1061 U 2395
EmsVideo_1_Client 942.37317727 TX 1012 1061 U 2398
EmsVideo_1_Client 942.377 RX 64 113 U 2397
WebBrowsingGraphics_0_Server 942.38092876 TX 1024 1073 U 2399
WebBrowsingGraphics_0_Client 942.394 RX 1024 1073 U 2399
AvlAssetPerimeter_1_Server 942.42492988 RX 1408 1457 U 2401

Used to measure KPIs





Visualization

- No preferred visualizer for ns-3
- Two tools have been developed over the years, with some scope limitations
  - Pyviz
    - FlowMonitor (statistics with Pyviz linkage)
  - NetAnim (George Riley and John Abraham)
- Support is lagging for these tools (help wanted)

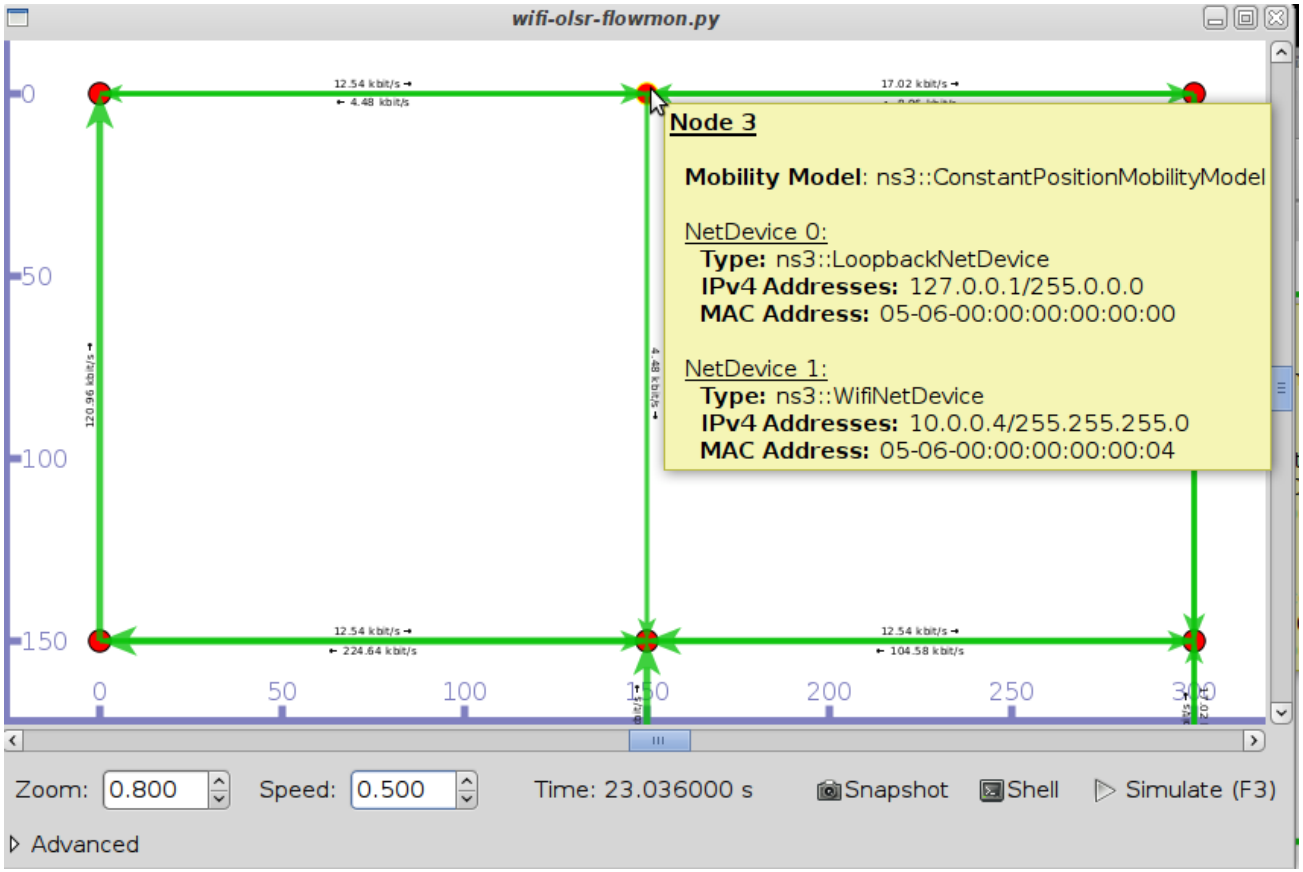
PyViz overview

- Developed by Gustavo Carneiro
- Live simulation visualizer (no trace files)
- Useful for debugging
  - mobility model behavior
  - where are packets being dropped?
- Built-in interactive Python console to debug the state of running objects
- Works with Python and C++ programs

Pyviz and FlowMonitor

- Example screenshot from:

```
./waf --run src/flow-monitor/examples/wifi-olsr-flowmon.py
--vis
```



Enabling PyViz in your simulations

- Make sure PyViz is enabled in the build

```
SQlite stats data output      : not enabled (library 'sqlite3' not found)
Tap Bridge                    : enabled
PyViz visualizer              : enabled
Use sudo to set suid bit      : not enabled (option --enable-sudo not selected)
```

- If program supports CommandLine parsing, pass the option

  `--SimulatorImplementationType=`

  `ns3::VisualSimulatorImpl`

- Alternatively, pass the "--vis" option

FlowMonitor

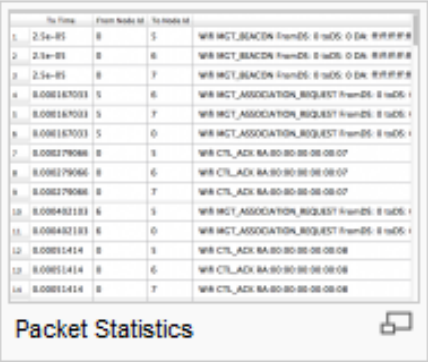
- Network monitoring framework found in `src/flow-monitor/`
- Goals:
  - detect all flows passing through network
  - stores metrics for analysis such as bitrates, duration, delays, packet sizes, packet loss ratios

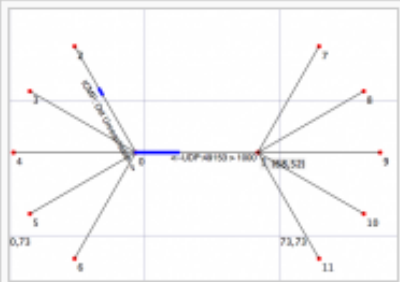
Plan to discuss more on Tuesday

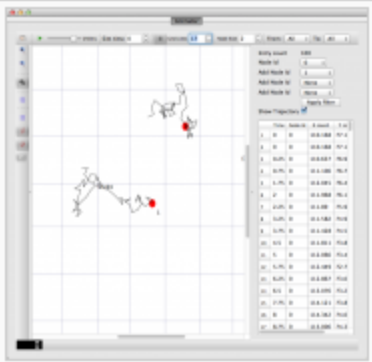
G. Carneiro, P. Fortuna, M. Ricardo, "FlowMonitor-- a network monitoring framework for the Network Simulator ns-3," Proceedings of NSTools 2009.

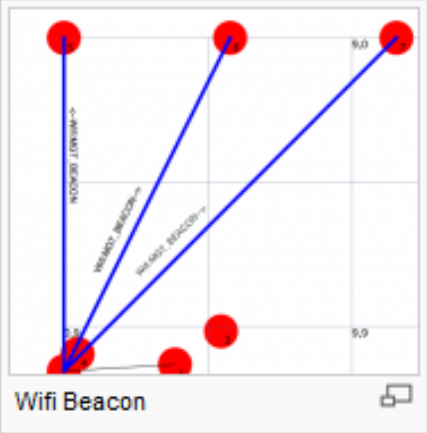
NetAnim

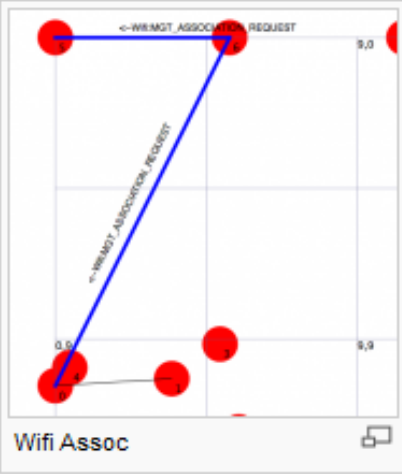
- "NetAnim" by George Riley and John Abraham

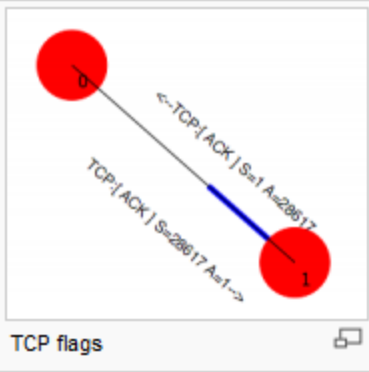

Packet Statistics


Dumbbell


Node Trajectory


Wifi Beacon


Wifi Assoc


TCP flags

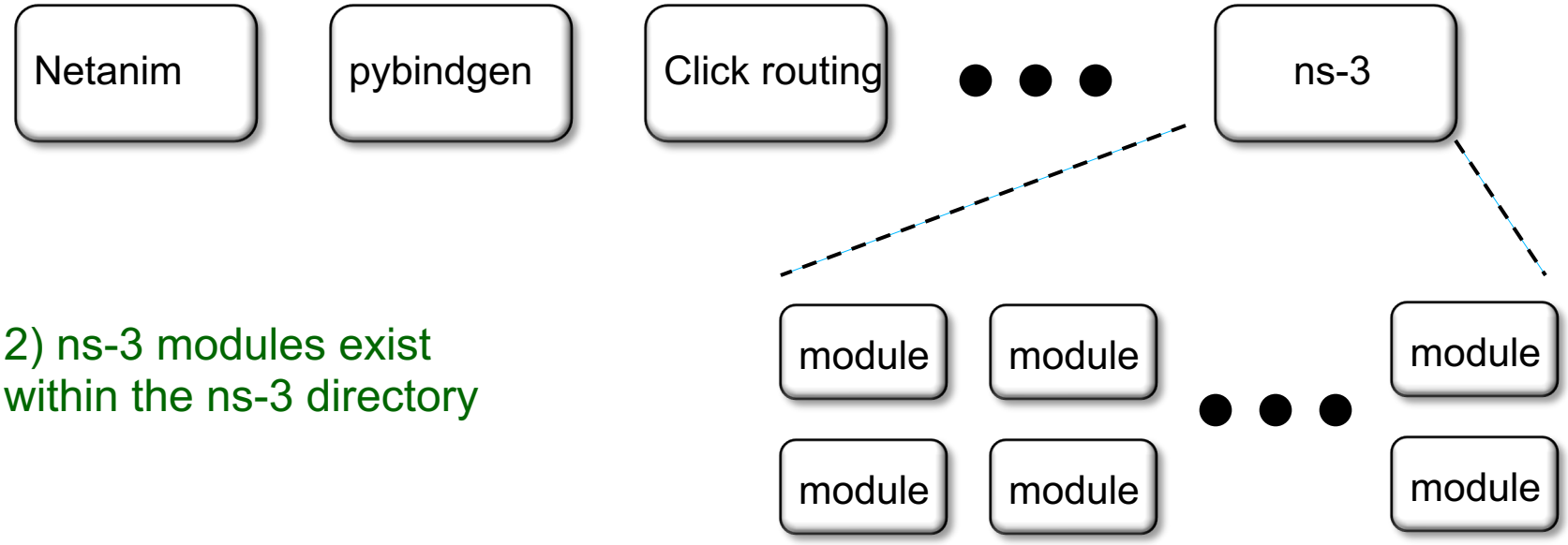
NetAnim key features

- Animate packets over wired-links and wireless-links
  - limited support for LTE traces
- Packet timeline with regex filter on packet meta-data.
- Node position statistics with node trajectory plotting (path of a mobile node).
- Print brief packet-meta data on packets

Software organization

- Two levels of ns-3 software and libraries

1) Several supporting libraries, not system-installed, can be in parallel to ns-3



2) ns-3 modules exist within the ns-3 directory

Typical module source code organization

model/

examples/

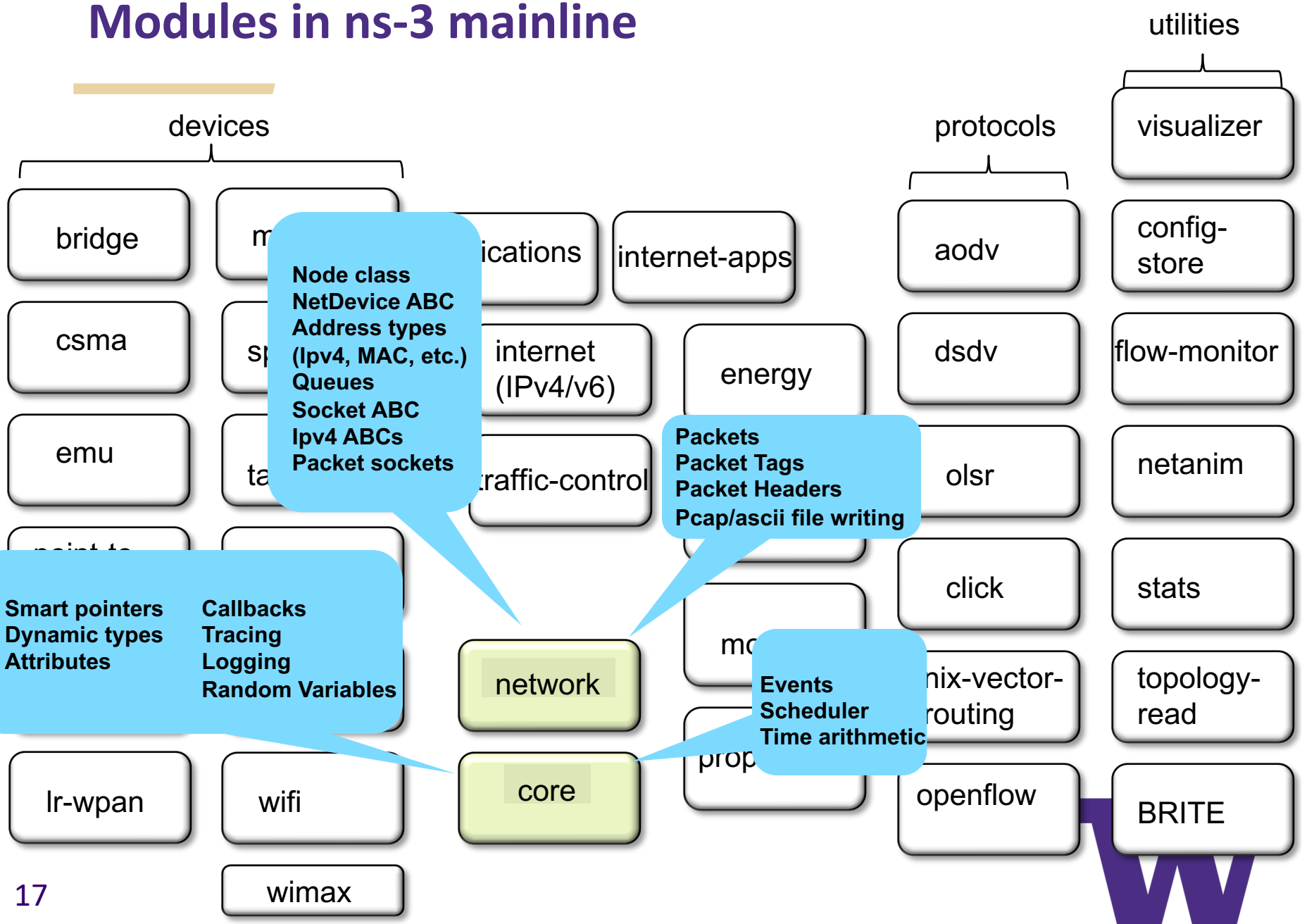
test/

bindings/

doc/

wscript/

Modules in ns-3 mainline

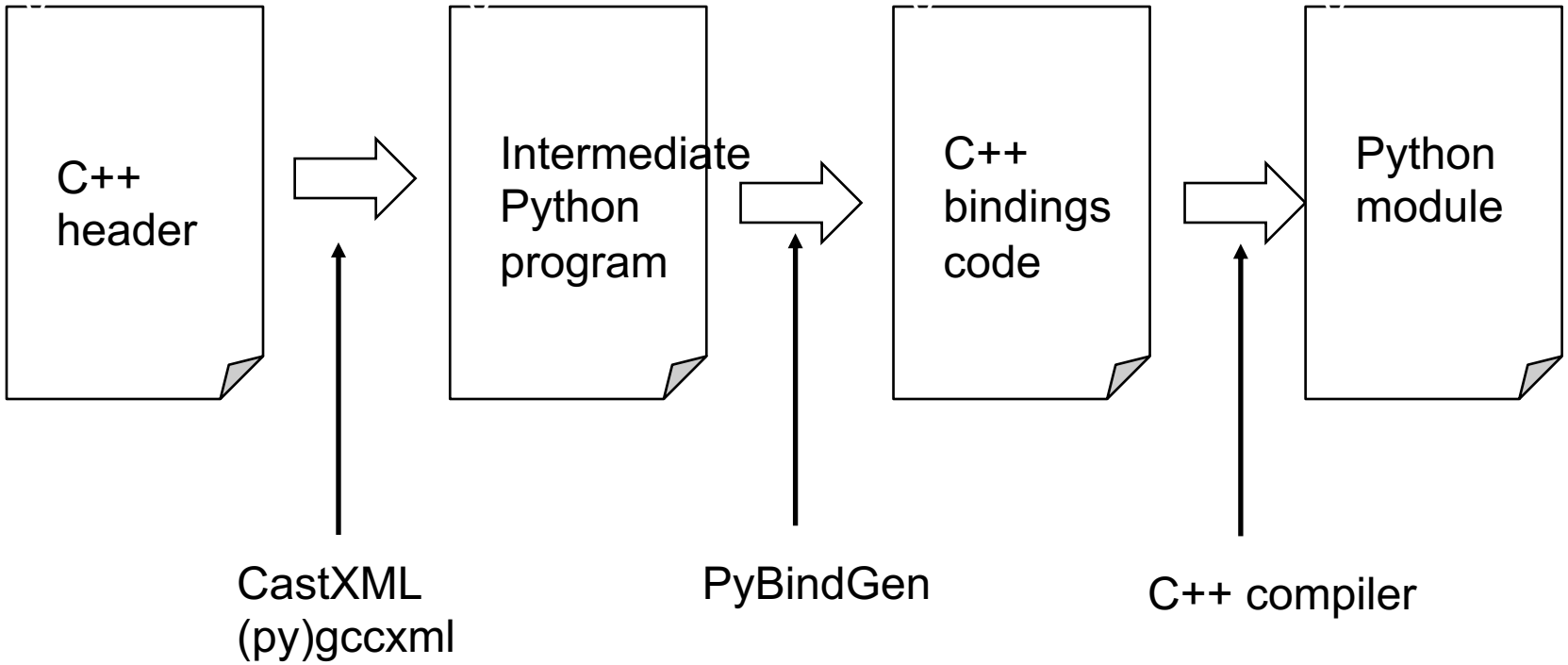


ns-3 programs

- ns-3 programs are C++ executables that link the needed shared libraries
  - or Python programs that import the needed modules
- The ns-3 build tool, called 'waf', can be used to run programs
- waf will place headers, object files, libraries, and executables in a 'build' directory

Python bindings

- ns-3 uses a program called PyBindGen to generate Python bindings for all libraries



Python bindings status

- API scanning for Python used to use a tool called gccxml
- ns-3 has moved to the successor, CastXML
  - requires a development installation of clang
- Automated testing currently only for Linux 64-bit systems
  - MacOS API scanning is not tested

waf operation

- This slide is a placeholder to demonstrate Waf operation
  - ‘`waf build`’ will compile and link source code into executables
  - ‘`waf --run`’ will run an executable in a special shell that knows the path to ns-3 libraries
  - New option: ‘`waf --run-no-build`’ will skip the build step

waf configuration

- Key waf configuration examples

```
./waf configure
    --enable-examples
    --enable-tests
    --disable-python
    --enable-modules
```

- Whenever build scripts change, need to reconfigure

Demo: `./waf --help`
`./waf configure --enable-examples --enable-tests --enable-modules='core'`
Look at: `build/c4che/_cache.py`

wscript example

```
## -*- Mode: python; py-indent-offset: 4; indent-tabs-mode: nil; coding: utf-8; -*-

def build(bld):
    obj = bld.create_ns3_module('csma', ['network', 'applications'])
    obj.source = [
        'model/backoff.cc',
        'model/csma-net-device.cc',
        'model/csma-channel.cc',
        'helper/csma-helper.cc',
        ]
    headers = bld.new_task_gen(features=['ns3header'])
    headers.module = 'csma'
    headers.source = [
        'model/backoff.h',
        'model/csma-net-device.h',
        'model/csma-channel.h',
        'helper/csma-helper.h',
        ]

    if bld.env['ENABLE_EXAMPLES']:
        bld.add_subdirs('examples')

    bld.ns3_python_bindings()
```

waf build

- Once project is configured, can build via `./waf build` or `./waf`
- waf will build in parallel on multiple cores
- waf displays modules built at end of build

Demo: `./waf build`

Look at: `build/` libraries and executables

Running programs

- `./waf shell` provides a special shell for running programs
  - Sets key environment variables

```
./waf --run sample-simulator
./waf --pyrun src/core/examples/sample-simulator.py
```

Build variations

- Configuring a build type is done at waf configuration time
- debug build (default): all asserts and debugging code enabled

```
./waf -d debug configure
```

- optimized

```
./waf -d optimized configure
```

- static libraries

```
./waf --enable-static configure
```

Controlling the modular build

- One way to disable modules:
  - `./waf configure --enable-modules='a','b','c'`
- The `.ns3rc` file (found in utils/ directory) can be used to control the modules built
- Precedence in controlling build

  1) command line arguments

  2) .ns3rc in ns-3 top level directory

  3) .ns3rc in user's home directory

Demo how .ns3rc works

Building without wscript

- The scratch/ directory can be used to build programs without wscripts

Demo how programs can be built without wscripts

Integrating other tools and libraries

Other libraries

- more sophisticated scenarios and models typically leverage other libraries
- ns-3 main distribution uses optional libraries (libxml2, gsl, mysql) but care is taken to avoid strict build dependencies
  - The Waf wscripts can be consulted as examples
  - example: sqlite3 in src/stats/wscript
- the 'bake' tool (described later) helps to manage library dependencies
- users are free to write their own Makefiles or wscripts to do something special

CORE emulator

Networks and Communication Systems Branch

Focus Areas | Projects | Products | Organization

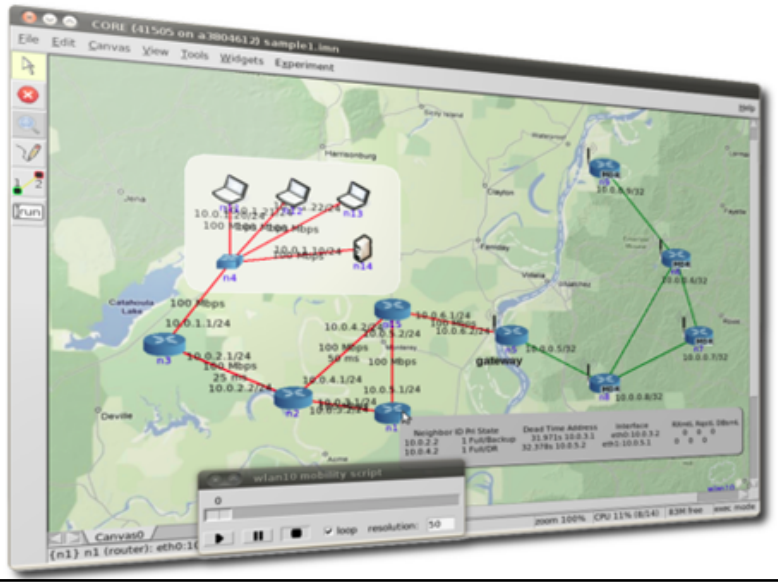
/ NRL / ITD / NCS / Common Open Research Emulator (CORE)

Common Open Research Emulator (CORE)

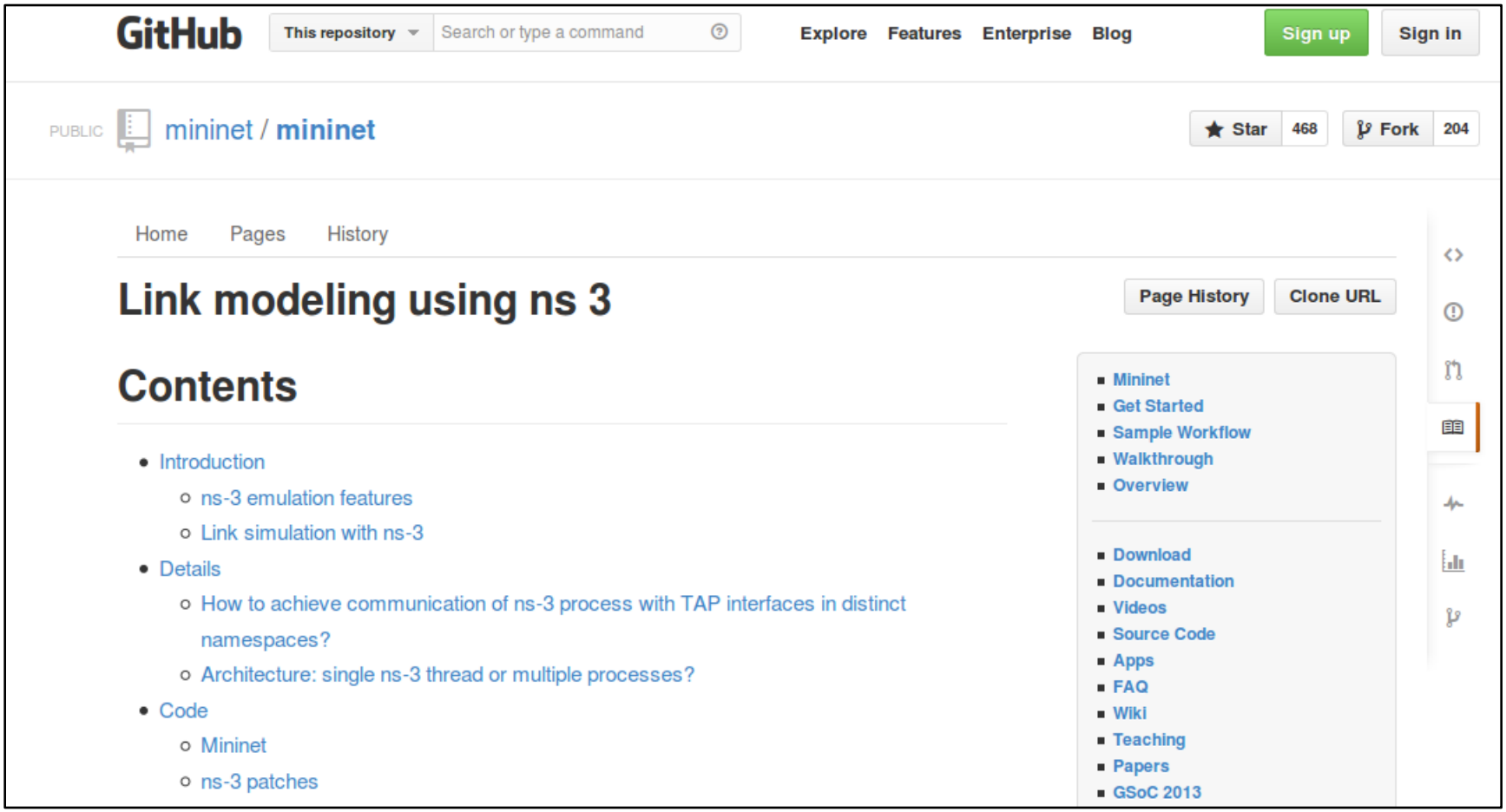
- NCS Home
- Focus Areas
- Projects
- Products
- Organization

The Common Open Research Emulator (CORE) is a tool for emulating networks on one or more machines. You can connect these emulated networks to live networks. CORE consists of a GUI for drawing topologies of lightweight virtual machines, and Python modules for scripting network emulation.

CORE



mininet emulator



Co-simulation frameworks have emerged

- PNNL's FNCS framework integrates ns-3 with transmission and distribution simulators

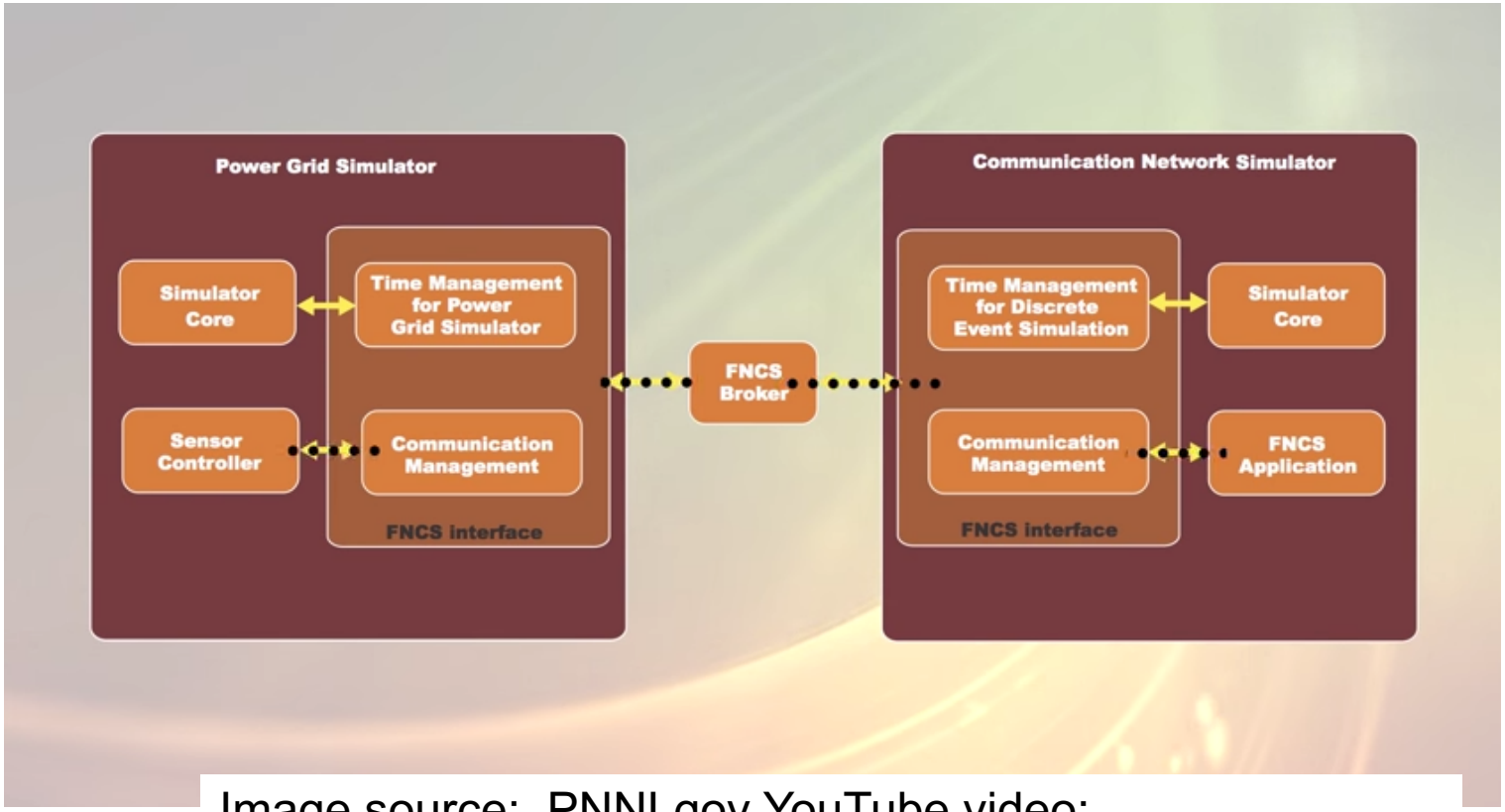
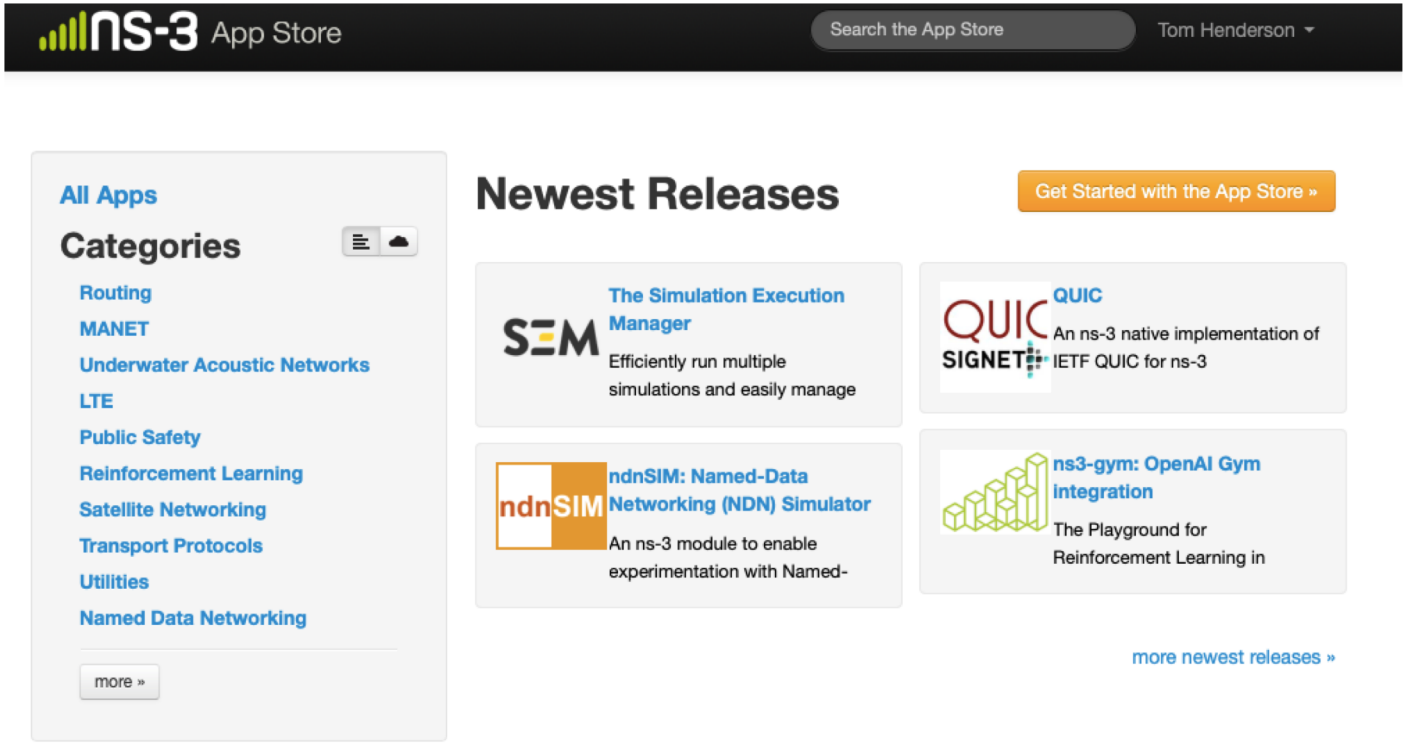


Image source: PNNLgov YouTube video:
Introducing FNCS: Framework for Network Co-Simulation

ns-3 App Store

- Project is migrating away from a centralized repository to a modular system called the 'ns-3 App Store'
  - https://apps.nsnam.org



Documentation overview

- Placeholder slide: online browsing of
  - Doxygen
  - ns-3 manual, model library, tutorial
  - wiki
  - command-line help