ndnSIM: a modular NDN simulator

http://ndnsim.net

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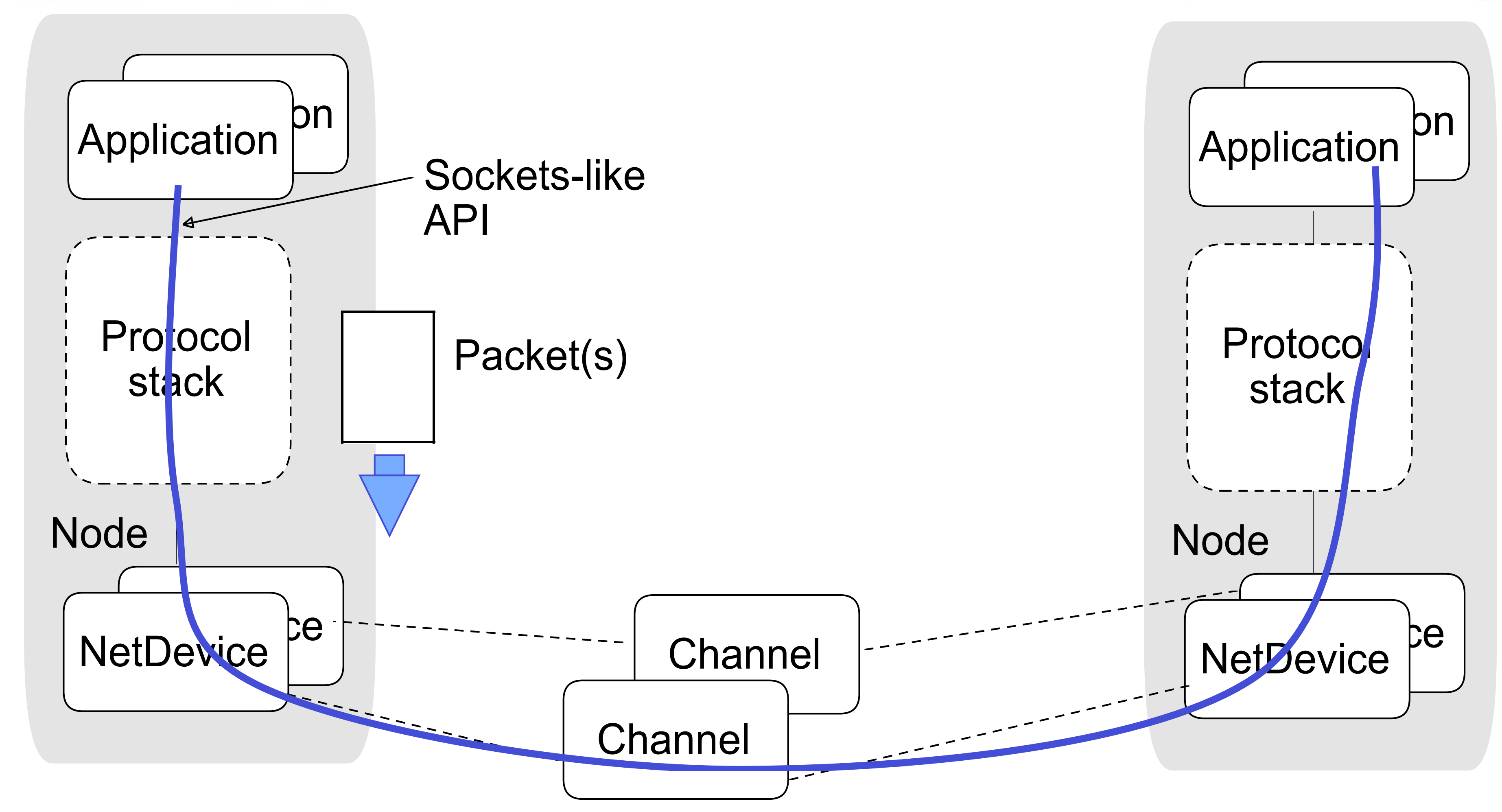
Goals

- Simulate basic NDN operations
- Packet-level interoperability with CCNx implementation
- Modular architecture
  - C++ classes for every NDN component
    - Face, PIT, FIB, Content store, and Forwarding strategey
- Scenario-defined module selection
  - Different management schemes for PIT
  - Different replacement policies for content store
  - Different forwarding strategies
- Ease of extensions
- Ease of use: plug and experiment

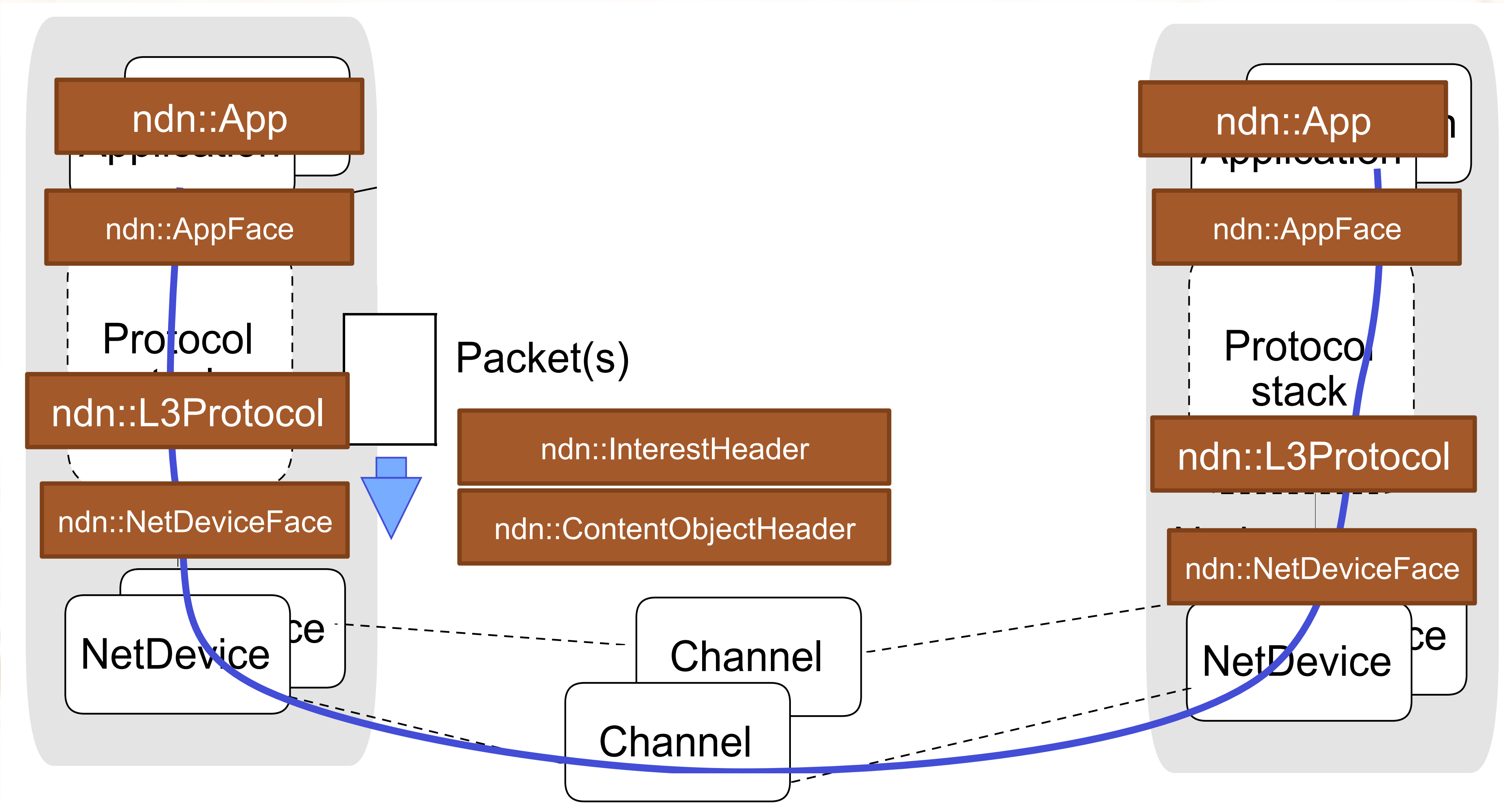
Ultimate Goal

- Establishing a *common* platform to be used by the community for all CCN/NDN simulation experimentations
  - So that people can compare/replicate results

Basic network simulation model in NS-3



ndnSIM extension of network simulation model



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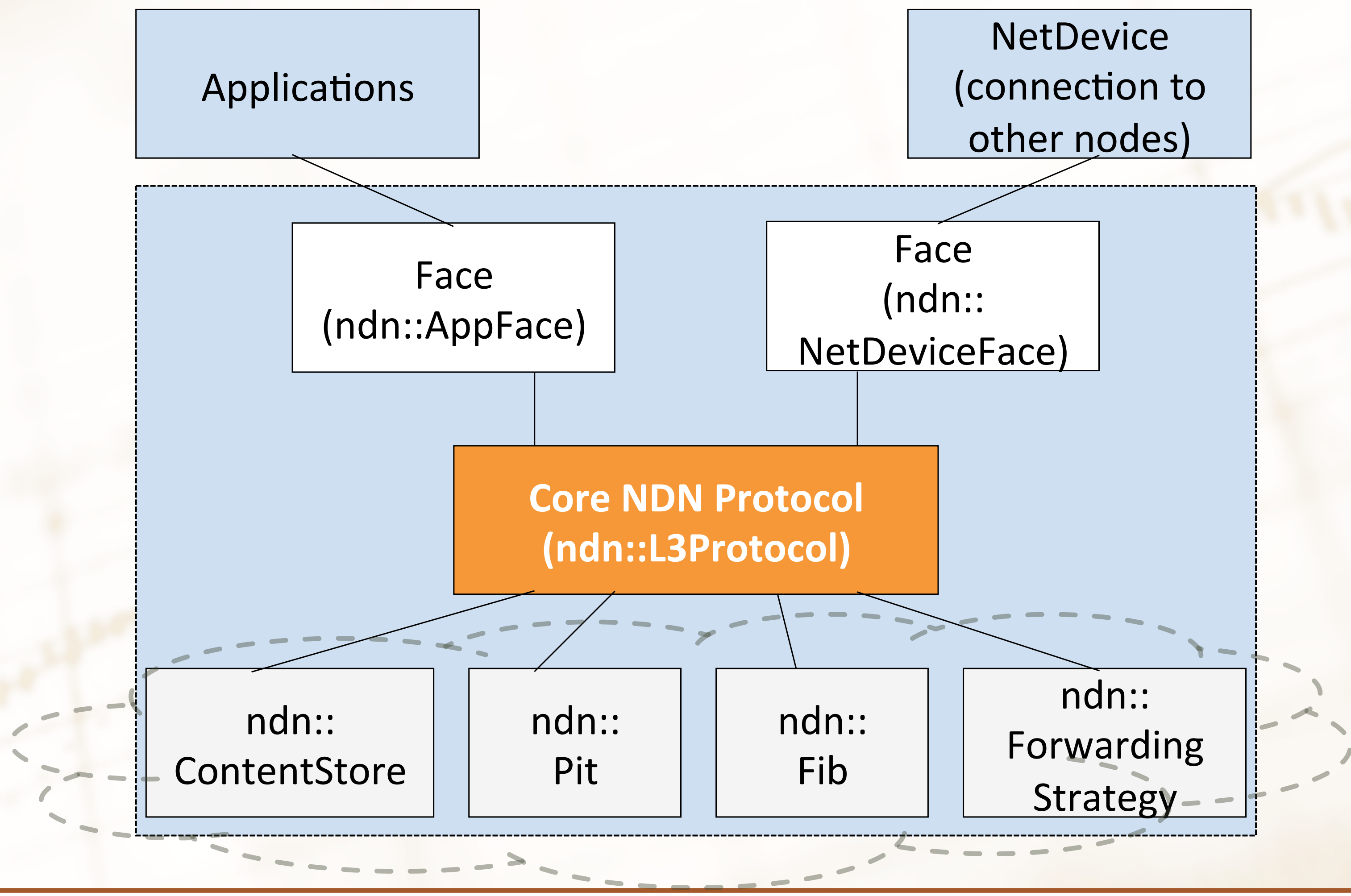
Node structure overview



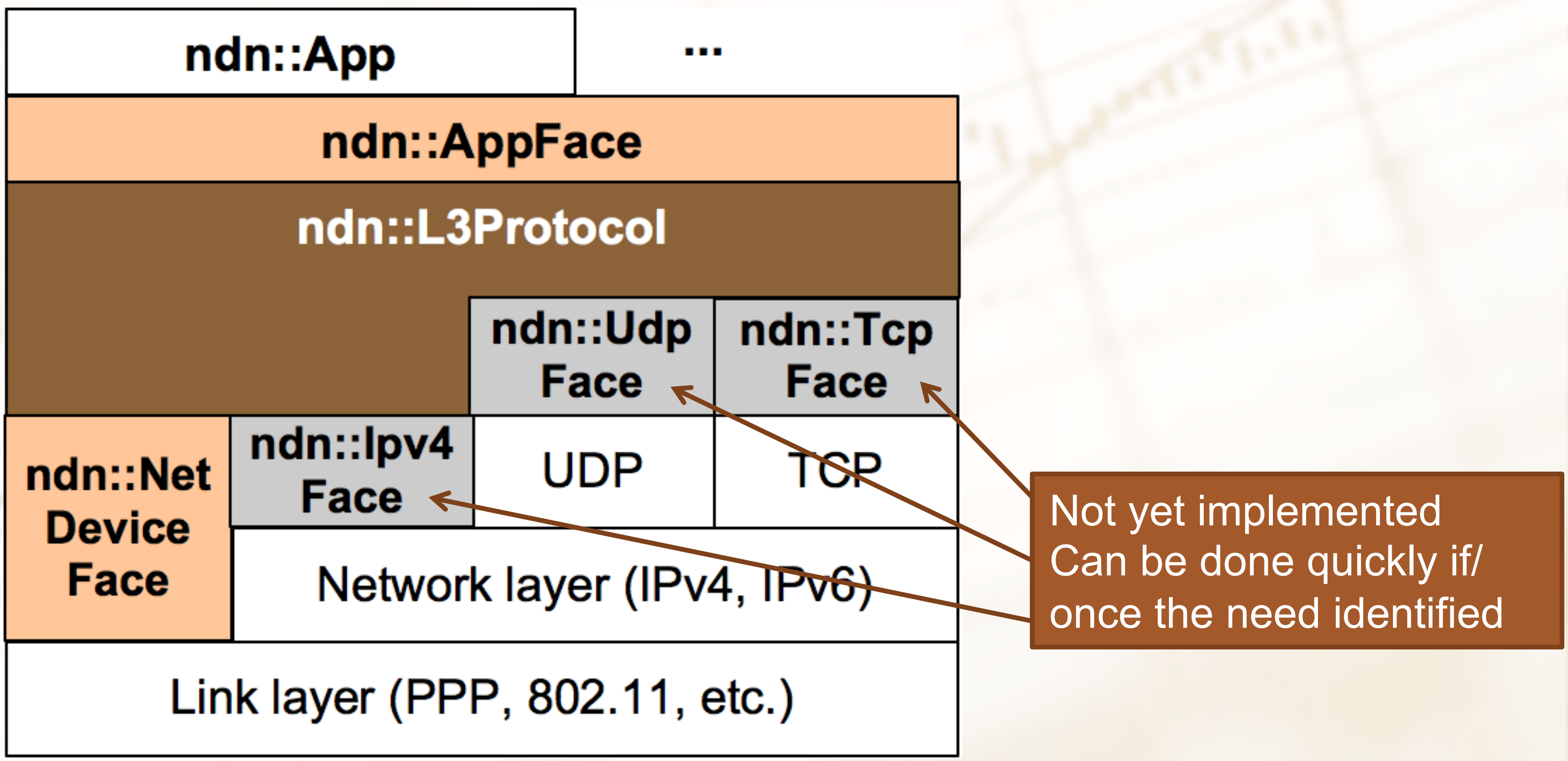
- Abstract interfaces of content store, PIT, FIB, and forwarding strategy.
- Each simulation run chooses specific scheme for each module

Core NDN protocol (ndn::L3Protocol)

- aggregates and manages all communication channels (Faces)
  - adding faces and registers necessary callbacks
  - removing faces
- receives packets from Faces and direct them to a scenario-selected forwarding strategy

Faces (ndn::Face)

- Abstraction from underlying protocols
  - callback registration-deregistration
  - packet encapsulation



Content Store

- In-network cache abstraction
  - add item
  - lookup item

- Currently available implementations of replacement policies
  - (default) Least-recently used (`ns3::ndn::cs::LRU`)
  - First-in-first-out (`ns3::ndn::cs::FIFO`)
  - Random (`ns3::ndn::cs::Random`)

- A desired content store module is selected and configured in simulation scenario

```
ndn::StackHelper ndnHelper;
ndnHelper.SetContentStore ("ns3::ndn::cs::LRU", "MaxSize", "100");
```

Pending Interest Table (PIT)

- Abstraction to maintain state for each forwarded Interest packet
  - Create, Lookup, Erase entry
- Each PIT entry stores
  - Interest packet itself
  - list of incoming faces + associated info
  - list of outgoing faces + associated info
  - forwarding strategy tags
    - e.g., reference to a delayed processing queue
- Size of PIT can be limited in simulation scenario
  - Available policies for new PIT entry creation:
    - (default) persistent (`ns3::ndn::pit::Persistent`): a new entry will not be created if limit is reached
    - LRU (`ns3::ndn::pit::LRU`): when limit is reached, insertion of a new entry will evict the oldest entry
    - Random (`ns3::ndn::pit::Random`): when limit is reached, insertion will evict a random entry

Forwarding Information Base (FIB)

- Abstraction to store information about name prefixes
  - Add, Remove, LongestPrefixMatch

- Every FIB entry stores
  - prefix
  - list of (ranked) Faces
  - forwarding strategy tags
    - per-prefix limits, data-plane stats, etc.

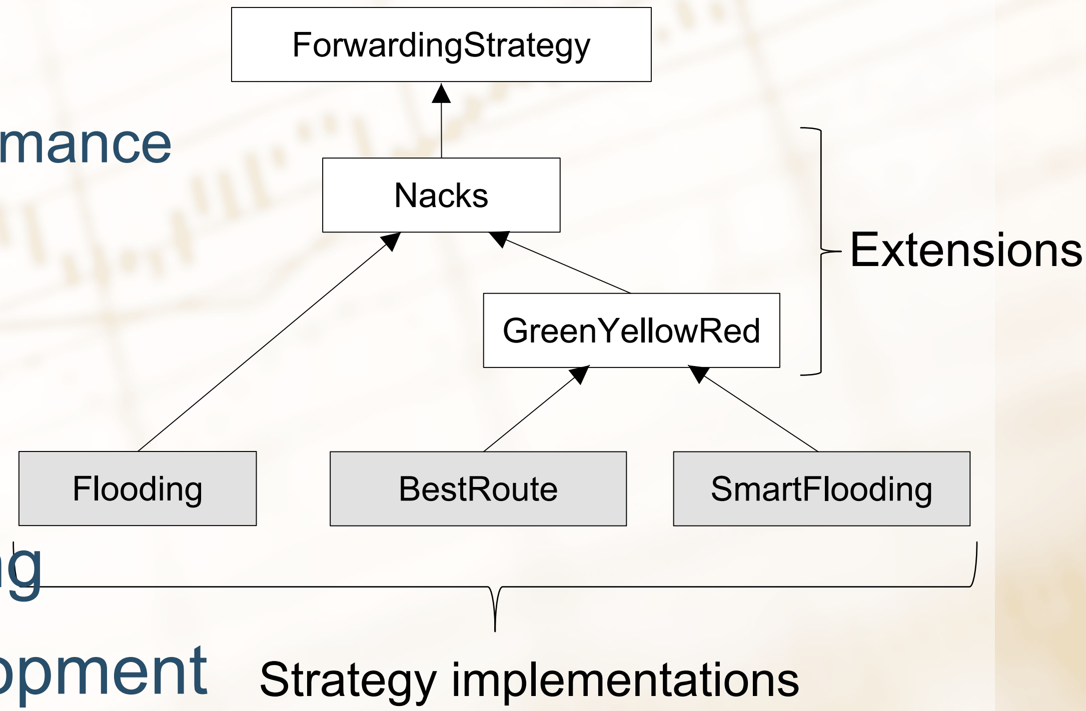
- FIB, PIT, and Content Store implemented as a trie-like structure
  - every name component is a node in a tree
  - node's children organized in a hash map
  - leafs contain pointers to FIB/PIT/CS entries

FIB population

- Manually
- Default route
  - all interfaces added to default route
  - forwarding strategy make a choice
- Global routing controller
  - calculate SPF
  - install a best-route for prefix
- May add support for quagga-based population
  - rely on Direct Code Execution NS-3 module
  - use real routing protocol implementations (e.g.NDN prefixes distribution by OSPFN)

Forwarding strategies

- Abstraction for Interest and Data processing
  - OnInterest, OnData, WillErasePendingInterest, RemoveFace, FailedToCreatePitEntry, DidCreatePitEntry, WillSatisfyPendingInterest, and many other overrideable events
- Extensions
  - NACKs
  - Data plane status performance
- Available strategies
  - Flooding strategy
  - Smart flooding strategy
  - Best-Route strategy
- Several other forwarding strategies under development right now



Simulator usage by early adopters & ourselves

- Forwarding strategy experimentation
  - behavior in the presence of
    - link failures
    - prefix black-holing
    - congestion
  - resiliency of NDN to DDoS attacks (interest flooding)
- Content-store evaluation
  - evaluation different replacement policies
- NDN for car2car communication
  - Evaluations of traffic info propagation protocols
- Exploration of SYNC protocol design
  - Experimentation of multiuser chat application whose design is based on SYNC (chronos)

NDN experimental extensions

- Interest NACKs to enable more intelligent, adaptive forwarding
- Congestion control by Limiting the number of pending Interests
  - per-face
  - per-FIB-entry
  - per-FIB-entry-per-face
- Satisfaction ratio statistics module
  - per-face (incoming/outgoing)
  - per-prefix
  - configurable time granularities
- A initial set of simple application modules

Interest NACK

- Solves dangling state problem
  - when router cannot satisfy nor forward, it sends Interest NACK
  - removes PIT entry
- Signals downstream to action
  - explore other paths to find destination
  - avoid congested paths
- Details
  - NACK code added to Interest
  - Interest NACK carries the same nonce
    - basic protection against spoofing
  - NACK codes
    - **Duplicate**
    - No data/no prefix
    - **Congestion**
    - ...

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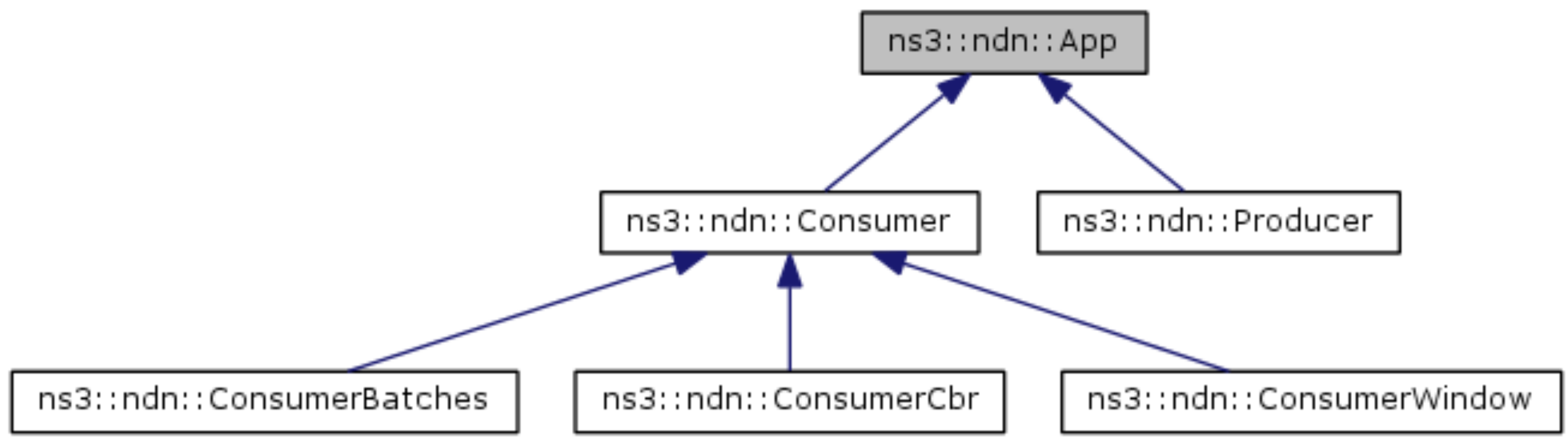
Limits on number of pending Interests

- Limit based on bandwidth-delay product
  - Assuming a know size (average) of interest packets
  - # interests = capacity / (AvgDataSize + AvgInterestSize)
- Different granularities
  - per face (incoming/outgoing), per prefix (FIB/PIT)
- Pending Interest removed by
  - received Data
  - timeout
  - (optionally) NACK
- Features
  - prevents congestion
  - provides base for DDoS protection mechanisms
  - may result in link underutilization

An initial set of applications



- **ndn::ConsumerCbr**
  - generates Interest traffic with predefined frequency
- **ndn::ConsumerBatches**
  - generates a specified number of Interests at specified points of simulation
- **ndn::Producer**
  - Interest-sink application, which replies every incoming Interest with Data packet

Scalability numbers

- Memory overhead (on average)
  - per simulation node
    - Node without any stacks installed: **0.4 Kb**
    - Node with ndnSIM stack (empty caches and empty PIT): **1.6 Kb**
    - For reference: Node with IP (IPv4 + IPv6) stack: **5.0 Kb**
  - per PIT entry: 1.0 Kb
  - per CS entry: 0.8 Kb
- Processing speed: on single core 2.4 Ghz cpu

  ~50,000 Interests per wall clock second

  ~35,000 Interests + Data combined per wall clock second
- MPI support of NS-3
  - manual network partitioning
  - close to linear scaling with number of cores with good partitioning

Other CCN Simulators

- ccnSim
  - primarily focused on cache behavior research
  - smaller memory footprint
    - more abstractions and simplifications
    - simplified Interest/Data packet formats (e.g., names restricted to number vectors?)
  - Not very modular for easy extension
- CCNPL-Sim
  - based on custom discrete event simulator (SSim)
  - limited flexibility for extensions
    - needs a content routing scheme as inter-layer between SSim and CCNPL-Sim?
    - How to use this for forwarding strategy experimentation?
- NS-3 Direct Code Execution + ccnd
  - most realistic evaluation of the prototype implementation
  - high per-node overhead
  - Difficult to experiment with different design choices
    - need to be implemented in real code first

Try out ndnSIM and let us know your thought/comments/bug reports/new feature requests !

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