Networks on Chip: A New Contract between Hardware and Software

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Overview

Current Trends

Makimoto's Pendulum

Nostrum Architecture and Protocol Stack

NoC Design Flow

NoC Programming Model

Summary

Current Trends

- Deep sub-micron effects make it harder to maintain global synchrony.
- Synthesis and compiler technology cannot bridge more than one abstraction level.
- Single chip applications become more heterogeneous.

Globally Asynchronous Locally Synchronous Designs

- The clock signal takes many cycles across the chip in a deep sub-micron gigahertz design.
- The clock tree consumes already up to 50% of the total power with increasing trend.
- Process variations on the chip lead to different clock signal delays.

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Trend for current and next technology generations:

- Synchronous regions of size 50 - 2000 k-Gates;
- Synchronous clusters (computing element + memory) communicate asynchronously over communication network.

Synthesis and Compiler Technology

- Synthesis technology can bridge only one shallow abstraction level.
- Compilers for C, Pascal, Fortran, etc. are very successful.
- Compilers for more abstract languages (Prolog, ML, Haskell, etc.) do not produce as efficient code.
- RTL synthesis (direct structural mapping with logic optimisation) is very successful.
- High level synthesis (resource allocation, binding, scheduling) does not produce as efficient designs.

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Current trend:

- Designer responsibility:
  - ⋆ Functional model of behaviour of synchronous cluster;
  - ⋆ Precise specification of communication semantics;
  - ⋆ Assignment of tasks to resources;
- Synthesis tools:
  - ⋆ Traditional compilation/synthesis of a synchronous cluster;
  - ⋆ Direct refinement and mapping of communication onto provided communication services;

Heterogeneous Applications

Most applications grow by accumulating diverse functionality.

- Mobile phone ⇒ mobile office
  (phone + email + Internet + word processing + calendar + language translation + ...)
- Car GPS ⇒ navigation assistant (GPS + maps + tourist guide + traffic information system + ...)

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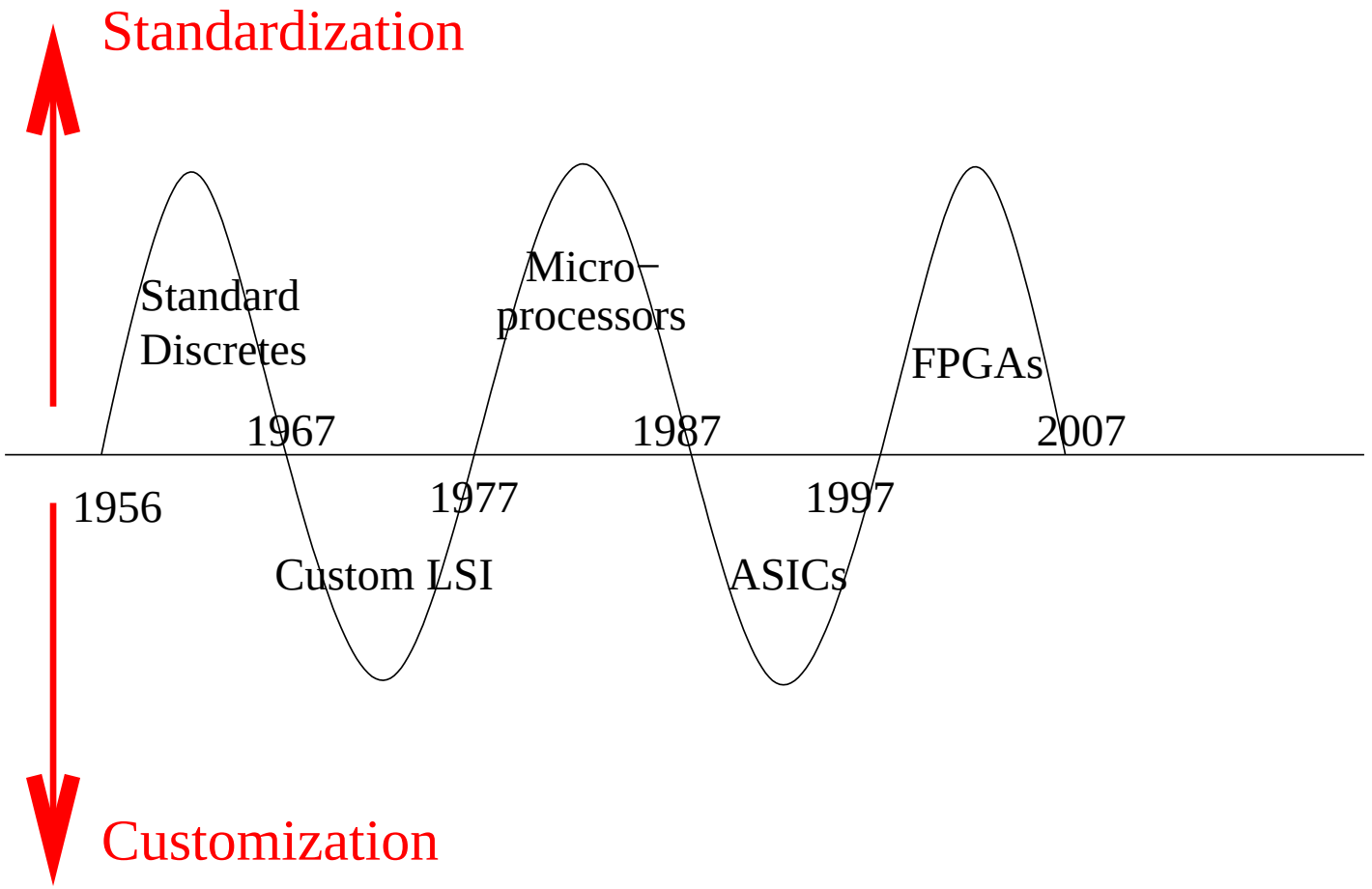
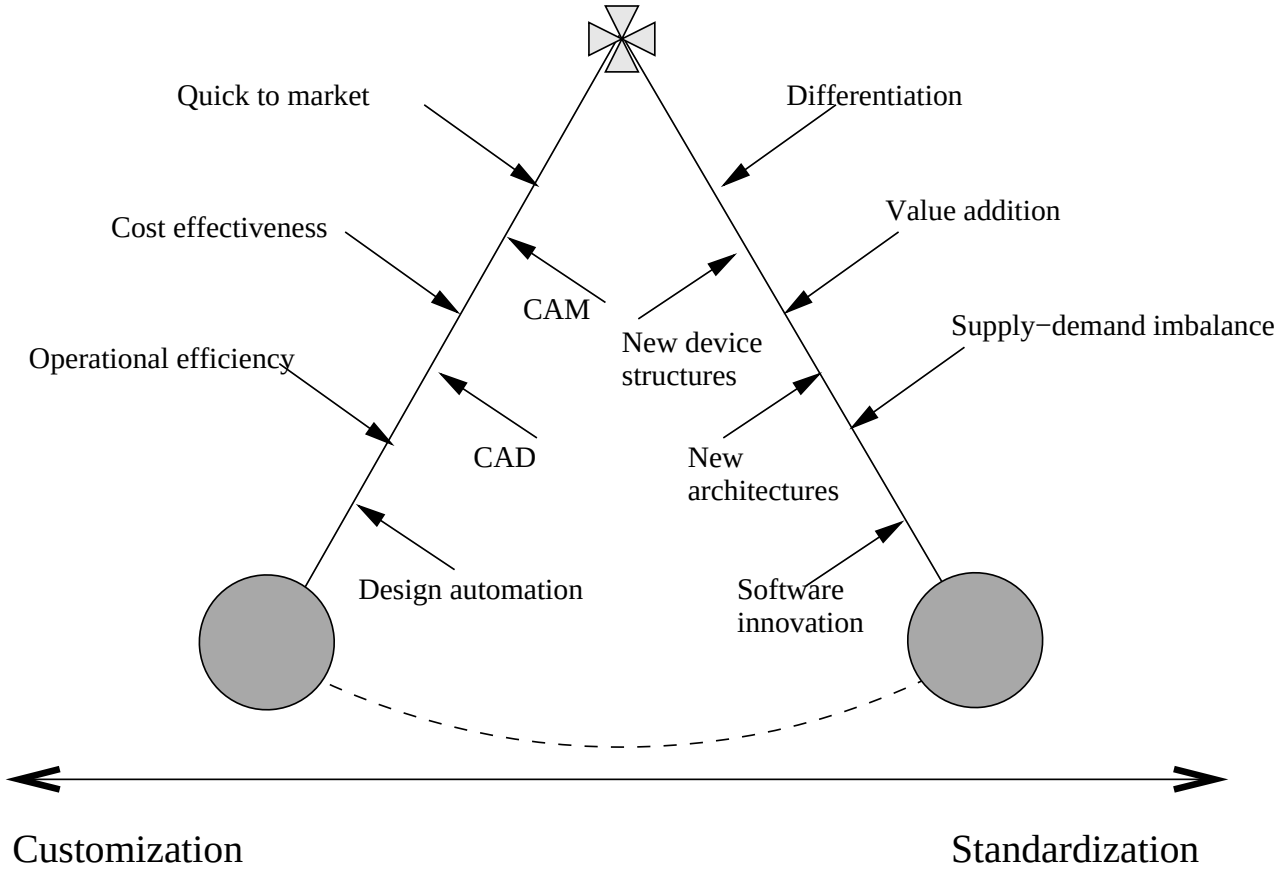
Current trend:

- Ever more complex IPs (components, functions, ...) are reused.
- A function with its implementation (IP) is reused in new applications.
- Search for well defined interfaces to connect IPs (VCI, Amba, OCP, ...).

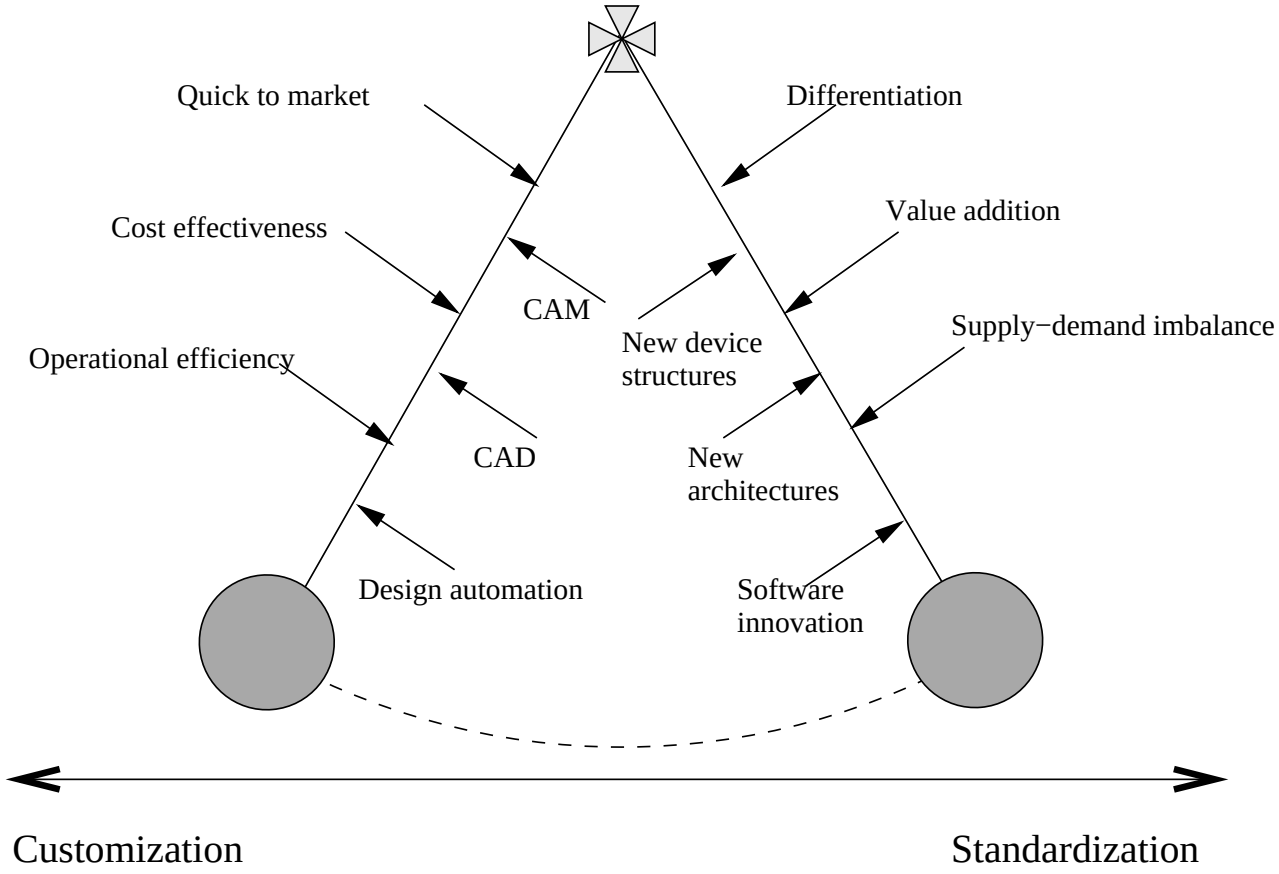
Makimoto Waves



Makimoto's Pendulum



Makimoto's Pendulum



Current forces

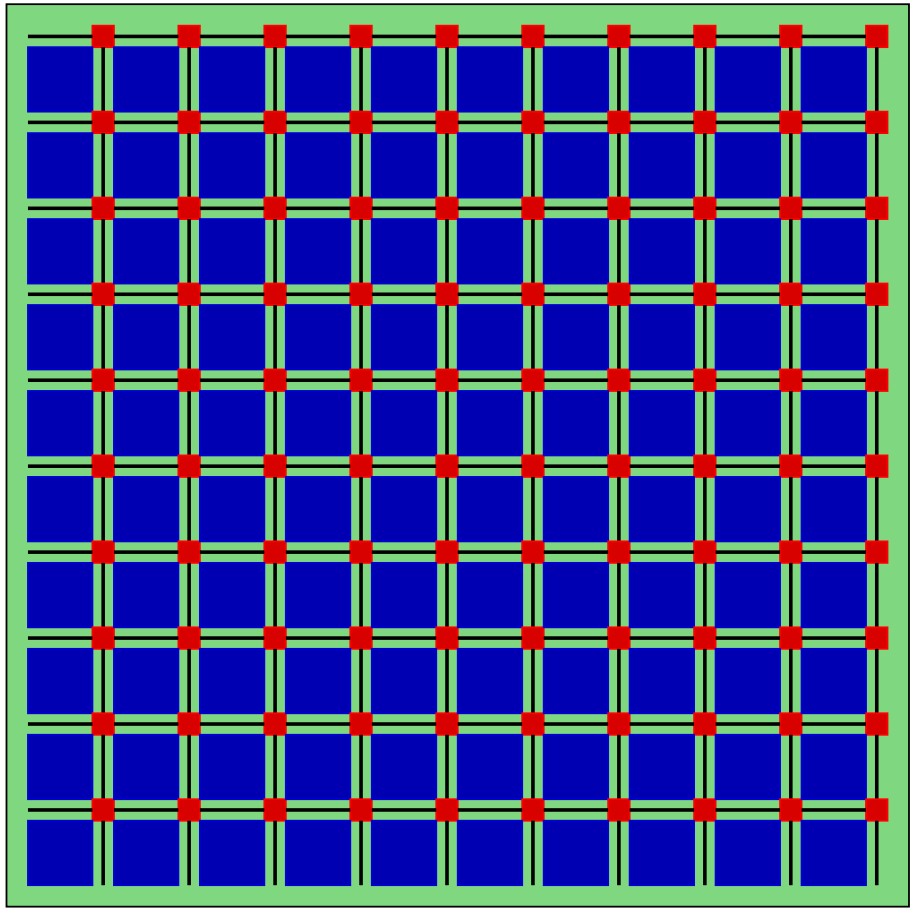
- Manufacturing cost efficiency (fabs, design costs, masks, testing),
- Demand for increased operational efficiency and maintenance efficiency,
- New technologies (deep sub-micron, memory, packaging)
- New architectures (FPGAs, ASIPs, platforms, NoCs)

push towards standardised platforms.

Summary of Observations and Trends

- Technology development
  ⇒**Locally synchronous clusters communicating asynchronously;**
- Application development
  ⇒**Integration of independently developed functions and features into new systems;**
- Desire to control costs
  ⇒**Standardization of manufacturing, operation and usage;**
- New technology, devices, architectures
  ⇒New possibilites and problems
  ⇒**Standardization of design flows and platforms;**

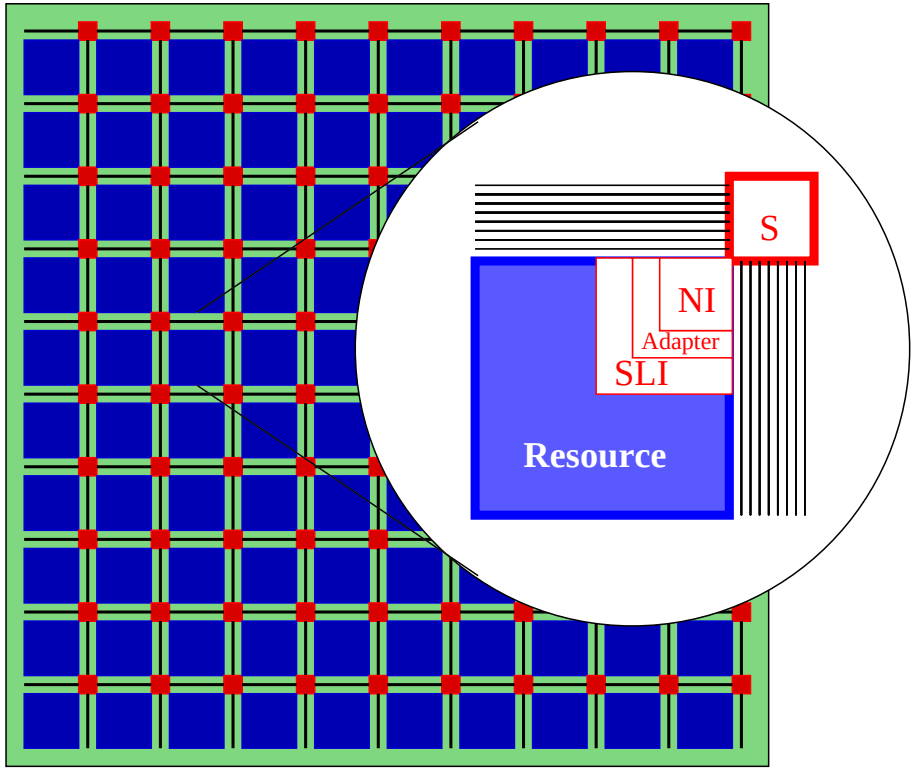
NoC Example: Nostrum



Characteristics:

- Regular 2-dimensional $k \times k$ mesh topology
- Resource-to-switch ratio: 1
- A switch is connected to 4 switches and 1 resource
- A resource is connected to 1 switch
- Average distance: $2/3k$
- Bisection: $2kw$

The Node in a Mesh



NI: Network Interface:

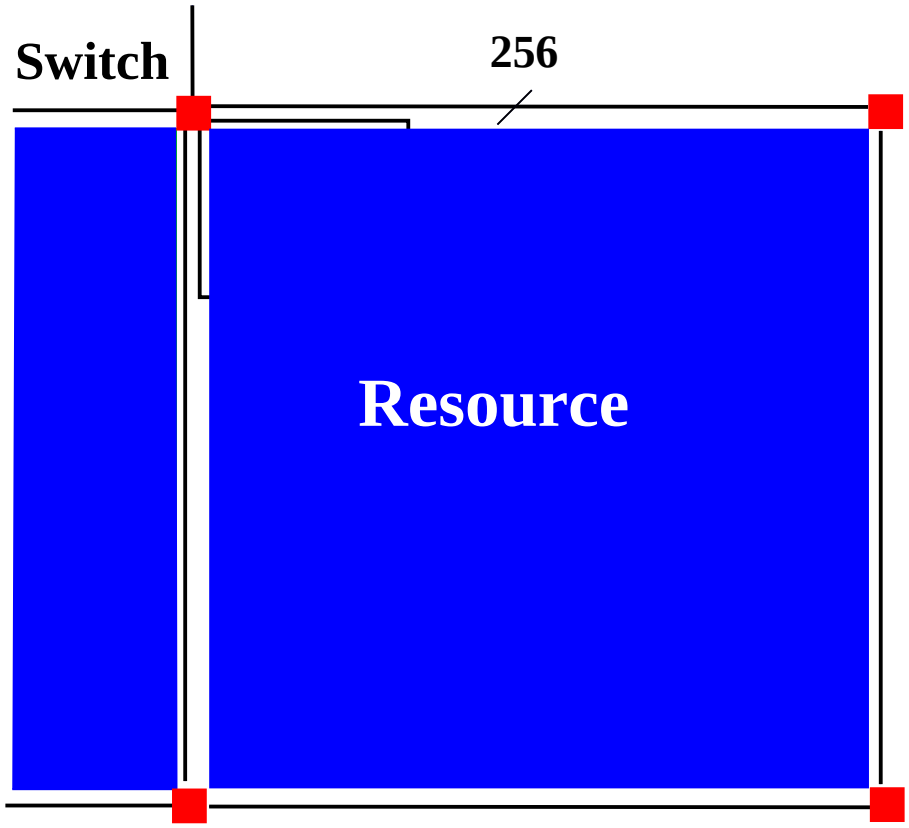
- Compulsory
- HW
- Implements the network layer protocol

Adapter: Resource specific interface circuit;

SLI: Session Layer Interface:

- Optional
- Hardware and/or software
- Implements the session layer protocol

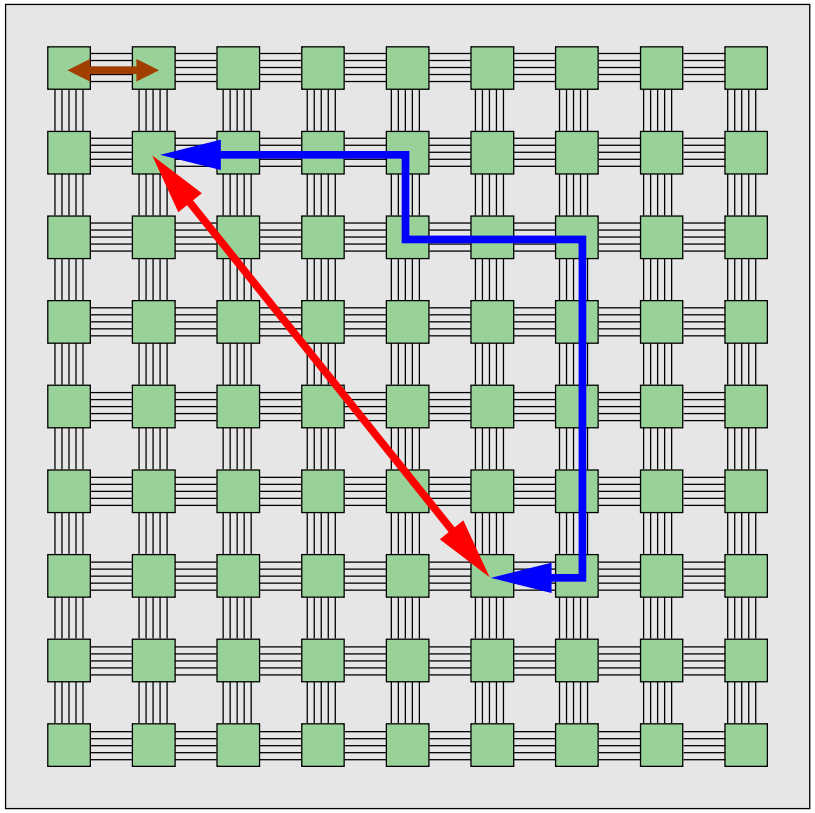
Node Geometry



Scenario:

- $60nm$ CMOS
- $22mm \times 22mm$ chip size
- $300nm$ minimal wire pitch
- $2mm \times 2mm$ resource
- $100\mu m \times 100\mu m$ switch
- switch-to-switch connection: 256 wires
- switch-to-resource connection: 256 wires

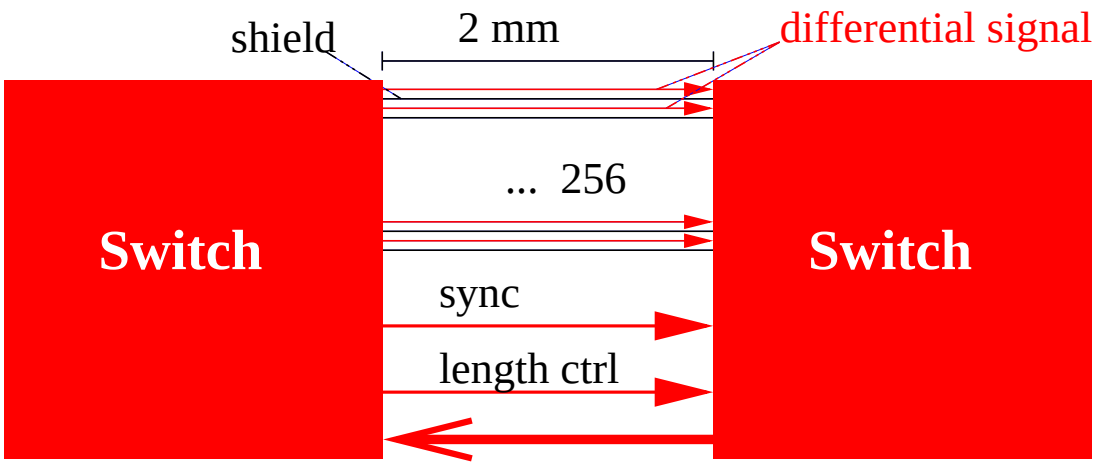
Communication is Key



Communication Layers:

- Physical layer: switch-to-switch and switch-to-resource
- Data link layer: switch-to-switch and switch-to-resource
- Network layer: resource-to-resource
- Session layer: process-to-process
- Application layer: application-to-application

Physical Layer



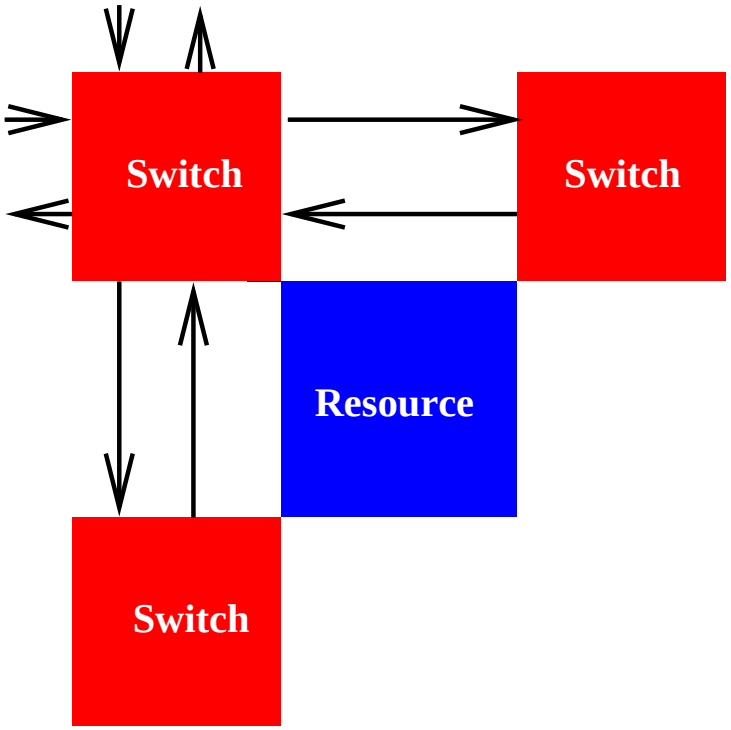
Parameters:

- Physical distance
- Number of lines
- Activity control
- Buffers and pipelining

Nostrum status:

- 128 data lines in each direction
- No pipelining
- On/off control for power saving

Data Link Layer



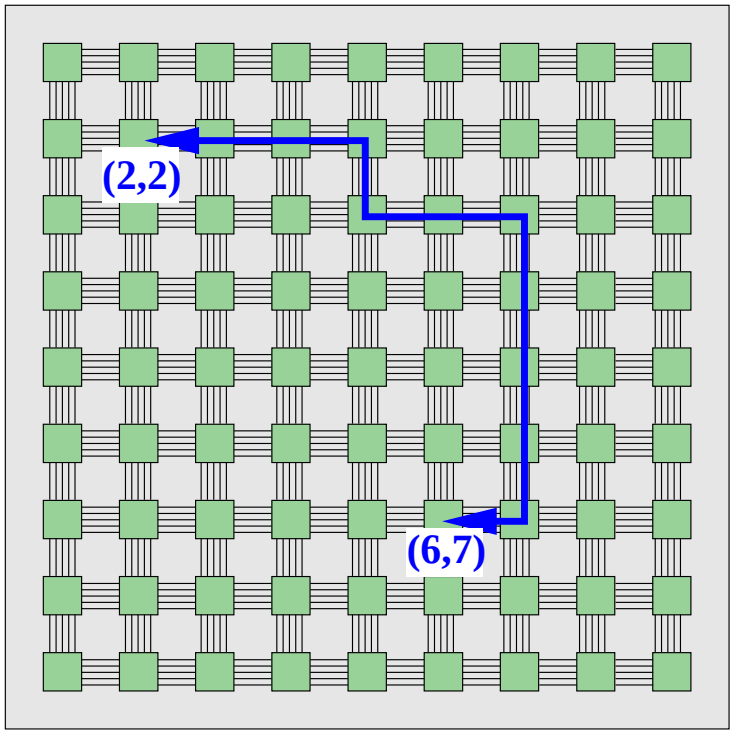
Parameters:

- Line frequency versus switch frequency
- Buffering
- Error correction
- Power optimization encoding

Nostrum status:

- Physical packet = data link packet
- Physical clock = data link clock
- Single packet input buffer
- Error correction
- On/off activity control

Network Layer



Parameters:

- Link layer cell size vs. network layer packet size
- Network address scheme
- Routing algorithm
- Priority classes
- Error correction

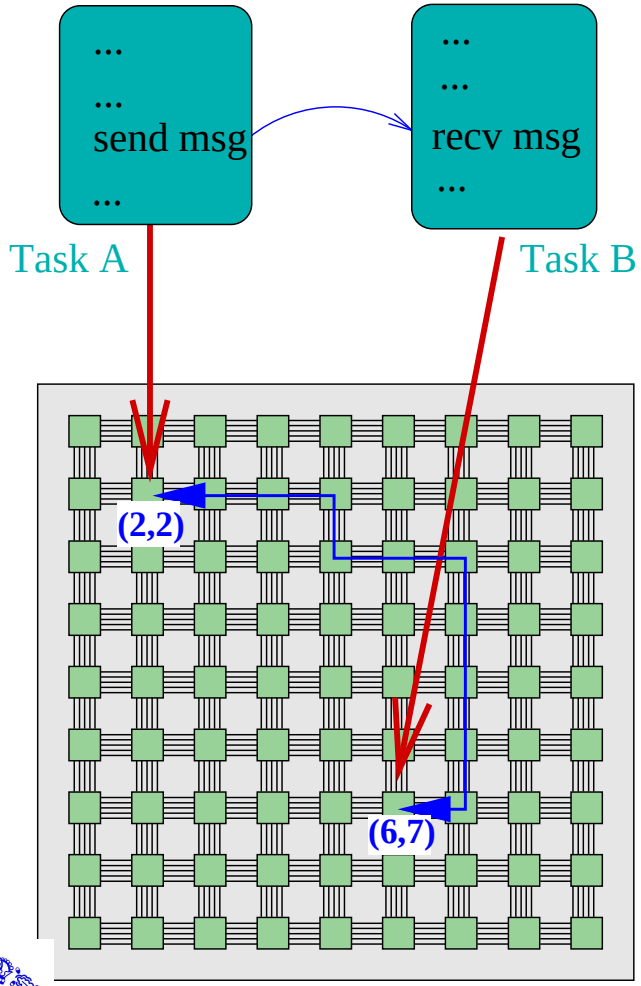
Nostrum status:

- Link layer packet = network layer packet
- Relative x-y addresses
- Deflective routing with no buffers and no routing tables
- Virtual circuits with guaranteed bandwidth and delays
- No error protection

Network Layer Services

- Packet switched best effort service
  - ⋆ Packets are guaranteed to arrive
  - ⋆ Packet payload may be protected (4 levels of protection)
  - ⋆ Load dependable delay in the network
  - ⋆ Load dependable delay at the network access point
- Virtual circuit service
  - ⋆ Guaranteed bandwidth
  - ⋆ Guaranteed maximum delay
  - ⋆ Multicast circuits
  - ⋆ Based on packet switching service

Session Layer



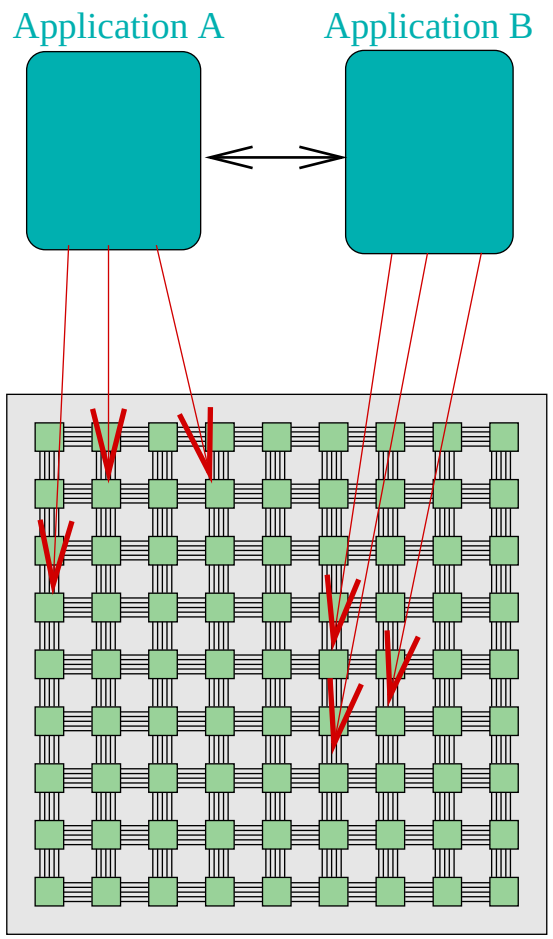
Parameters:

- Task level communication primitivs
- Message passing
- Shared memory based communication
- Synchronization
- Error correction

Nostrum status:

- Set of communication primitivs defined
- Both message passing and shared memory
- User controlled synchronization
- Optional end-to-end data protection

Application Layers



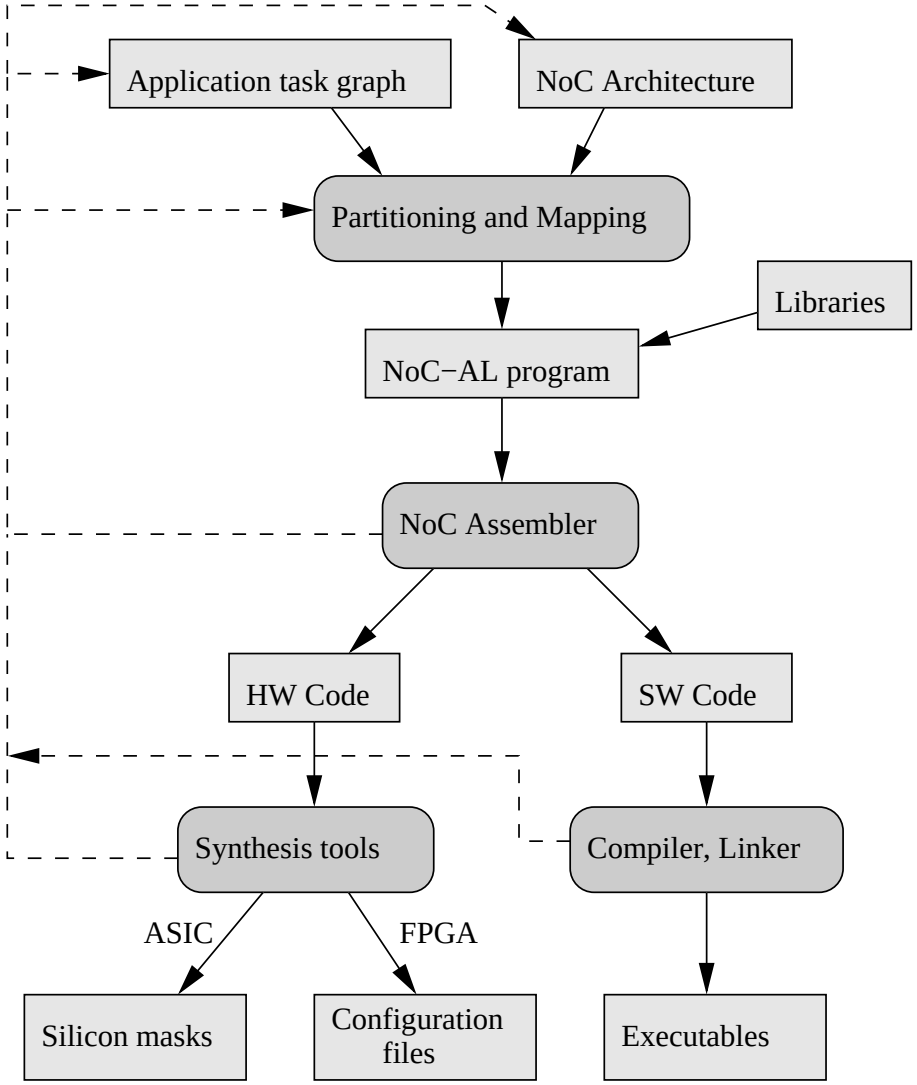
Application specific communication services;
E.g. the NoC operating system could use:

- Task/resource database access protocol
- Task migration protocol

What a NoC based Platform Offers

- A set of resource slots;
- Well defined set of communication services with performance characteristics;
- Resource management services;
- A design methodology for
  - ⋆ Network configuration and allocation;
  - ⋆ Resource implementation;
  - ⋆ Communication refinement.

NoC Based Design Flow



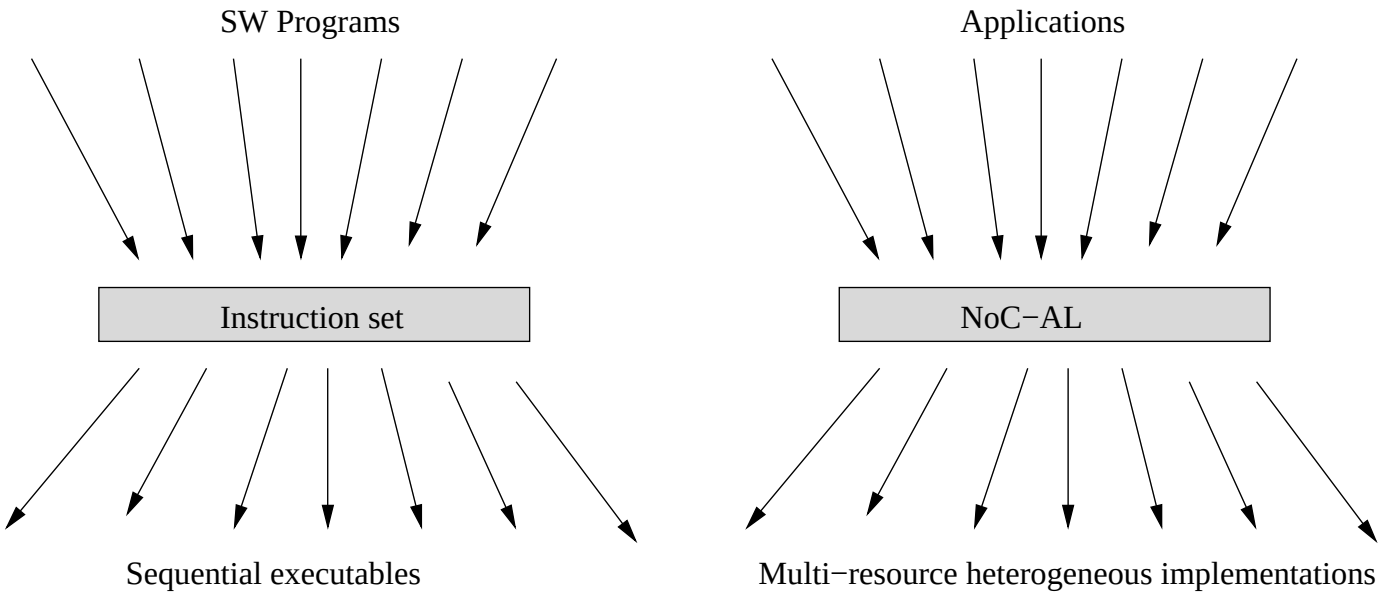
NoC Assembler Language Program Example

```
NoC Architecture
{ Topology: mesh 1 x 2
  Resource List: Row1: R1=SHARC DSP,
                       R2=ARM CPU}
NoC Application
{ R1: {#include <NoC-AL-SHARC.h>
       #include <f1.h>
       #include <f2.h>
       double in1,in2,out,x,y;
       int ch1=0, ch2=0, ach2=0;
    Process P11
    { while (1)
      { x=f1(in1,in2);
        while (ch1<=0) {ch1=channel(P11,P21);} //Open channel ch1 until success
        while (send(ch1,x)!=1) {continue;}}    //Wait for send to ch1 success
      while (close(ch1)!=1) {continue;}}       //Close channel ch1
    Process P12
    { while (1)
      { while (ach2<=0) {ach2=accept(&ch2);}   //Wait for channel ch2 accepted
        while (receive(ch2,y)!=1) {continue;}  //Wait for receive from ch2 success
        out=f2(y);}}}
```

NoC Assembler Language Program Example - cont'd

```
R2: {#include <NoC-AL-ARM.h>
     #include <f3.h>
     double a,b;
     int ch1=0, ch2=0, ach1=0;
  Process P21
  { while (1)
    { while (ach1<=0) {ach1=accept(&ch1);} //Wait for channel ch1 accepted
    while (receive(ch1,a)!=1) {continue;}  //Wait for receive from ch1 success
    b=f3(a);
    while (ch2<=0) {ch2=channel(P21,P12);} //Open channel ch2 until success
    while (send(ch2,b)!=1) {continue;}}    //Wait for send to ch2 success
    while (close(ch2)!=1) {continue;}}}}   //Close channel ch2
```

The NoC-AL Contract



- Defines NoC configuration;
- Defines functionality of processes;
- Defines functionality of inter-process communication;
- Defines performance of inter-process communication;
- Defines mapping of processes to resources;

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- A NoC implementation is a set of asynchronously communicating clusters.
- An application is modeled as a set of communicating processes.
- Communication is at the center of a NoC contract;
- The NoC contract is a natural extension of the IS/HDL contract;
- The extensions include task-resource mapping, communication functionality and communication performance;
- The NoC contract separates platform development from application development;
- It allows standardization of platforms and design flows.