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Gannet

Separation of Data flow and Control flow in Reconfigurable Multi-core SoCs using the Gannet Service-based Architecture

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- Overview
- Task control in NoC-based SoCs
- Gannet system
- Gannet language
- Separation of data flow and control flow

Overview

- We propose a novel approach to **separating control flow from data flow** in NoC-based SoCs consisting of multiple heterogeneous reconfigurable IP cores.
- This mechanism
  - enables full data path control by an embedded microcontroller
  - whilst avoiding the potential memory bandwidth bottleneck and
  - without requiring centralised control over the NoC.

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Overview

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- We assume a generic SoC where
  - data is processed by IP cores interacting through a NoC
  - control structures are implemented on a microcontroller.
- The proposed mechanism employs a service-based SoC architecture (the **Gannet** architecture) where
  - the control services are implemented using a Virtual Machine
  - IP cores acquire service behaviour through the use of a generic data marshalling and interfacing circuit.

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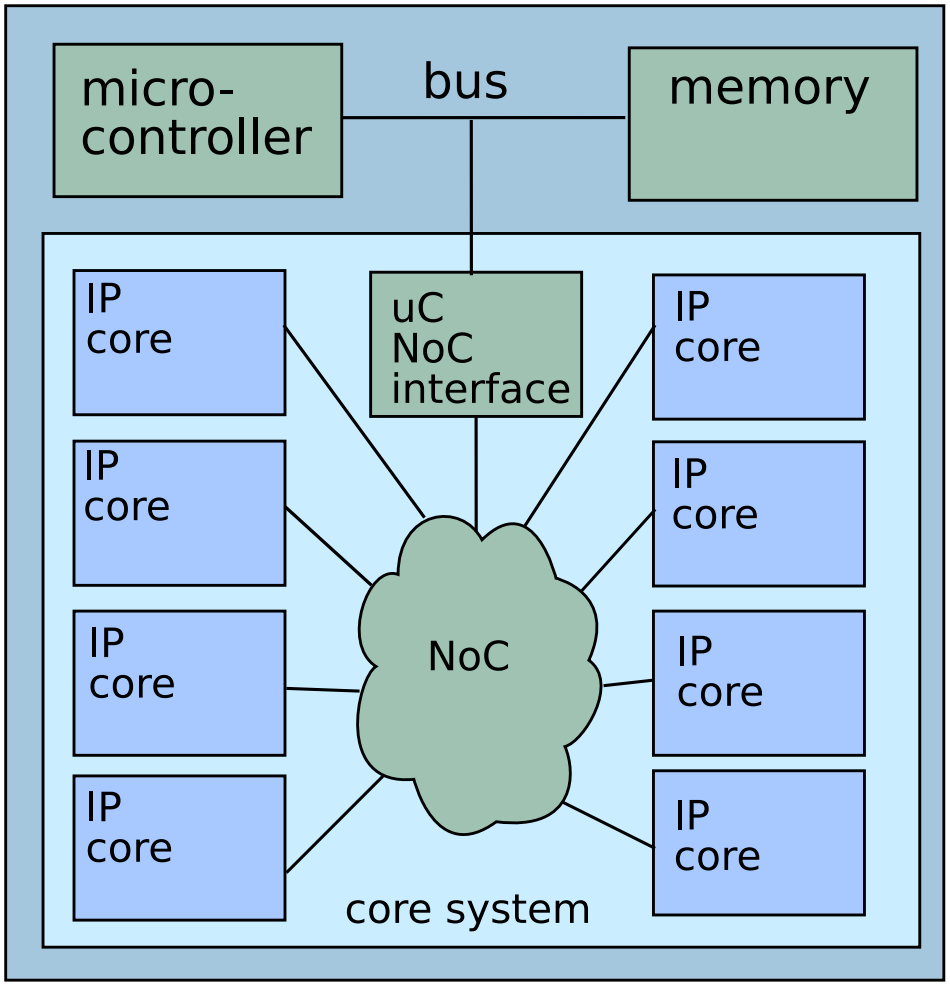
Task-level reconfigurability

Gannet

- NoC-based SoC with embedded microprocessor:



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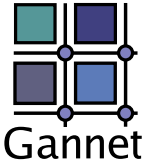
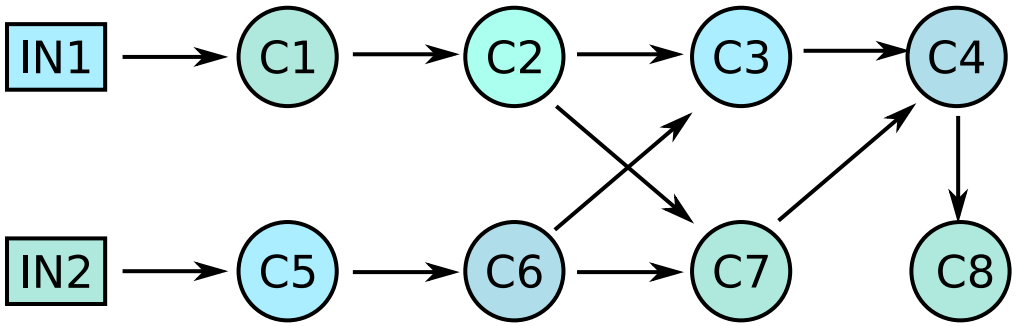
Task control in NoC-based SoCs



- SoCs in general use an embedded microprocessor for control.
- Conventional way of controlling hardware blocks using an embedded microprocessor: memory-mapped IO+ interrupts.
- In a NoC-based SoC, the microprocessor interacts with a NoC transceiver and transfers data as NoC packets $\Rightarrow$
  - efficient data transmission;
  - considerably reduction of required number of interrupts;
  - no significant operational difference with bus-based mechanism.

Task control in NoC-based SoC

- Non-task-level reconfigurable system:
  - microcontroller only sends control or configuration information to each core;
  - all data can flow between the cores.



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Task control in NoC-based SoC

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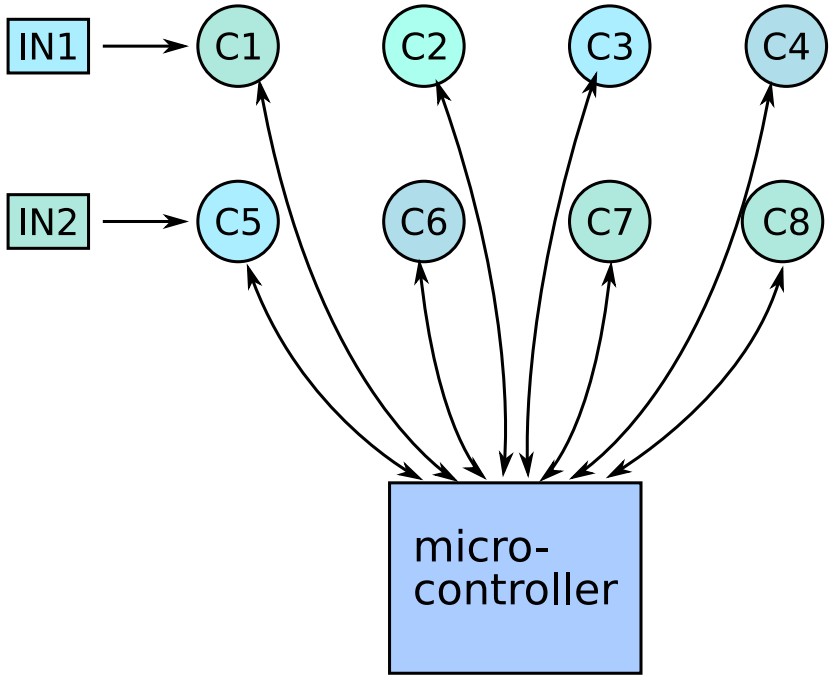
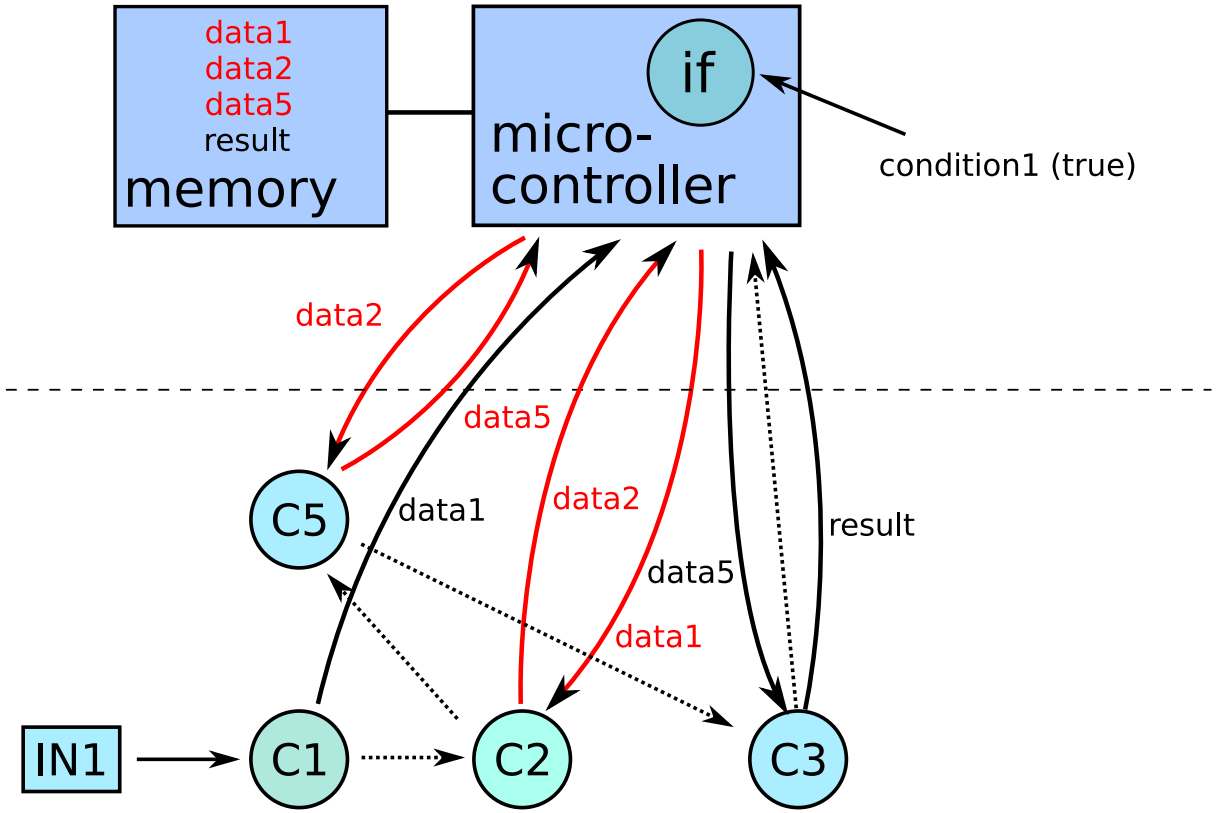
- Task-level reconfigurable system:
  - data paths are determined at run time by a program running on microcontroller;
  - all data pass via the microcontroller.



Example


```
Data* NoC_TRX(CoreAddres&,...); // variadic function prototype
/* variable declarations omitted */
data1=NoC_TRX(C1,IN1);
if (condition1) {
    Data* data2=NoC_TRX(C2,data1);
    data5=NoC_TRX(C5,data2);
} else {
    Data* data2=NoC_TRX(C5,data1);
    data5=NoC_TRX(C2,data2);
}
result=NoC_TRX(C3,data5);
```

Example


data1
data2
data5
result
memory
if
micro-
controller
condition1 (true)
data2
data5
C5
data1
data2
result
data5
data1
IN1
C1
C2
C3

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Gannet architecture

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- A **service-based** architecture for **very large SoCs:**
  - a collection of processing cores (HW/SW).
  - each core offers a a specific **service.**
  - tasks are defined by the interaction pattern of the services.
- Task-level reconfigurability
  - task description programs, configurable at run time
- High abstraction-level design
  - single program governs behaviour of complete system

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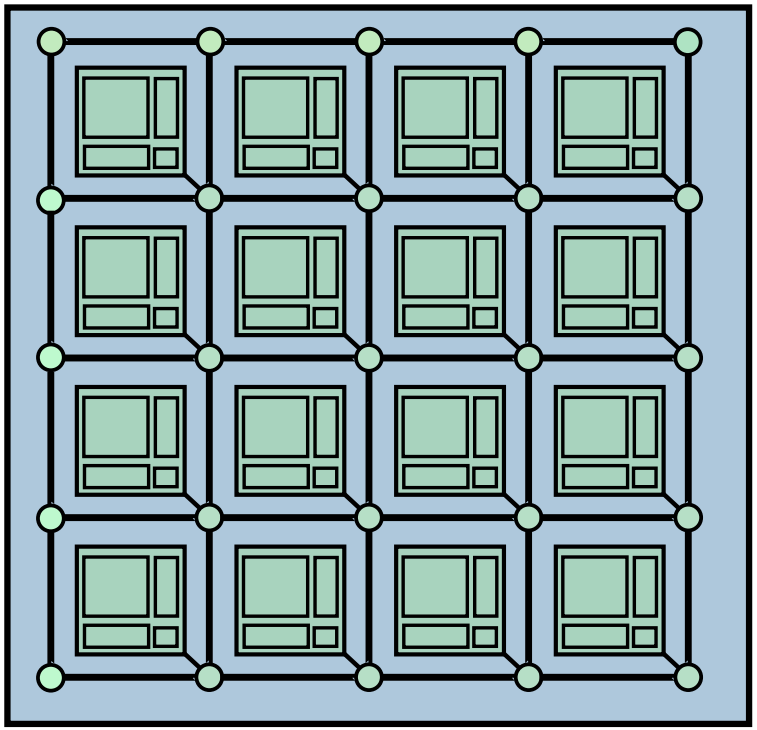
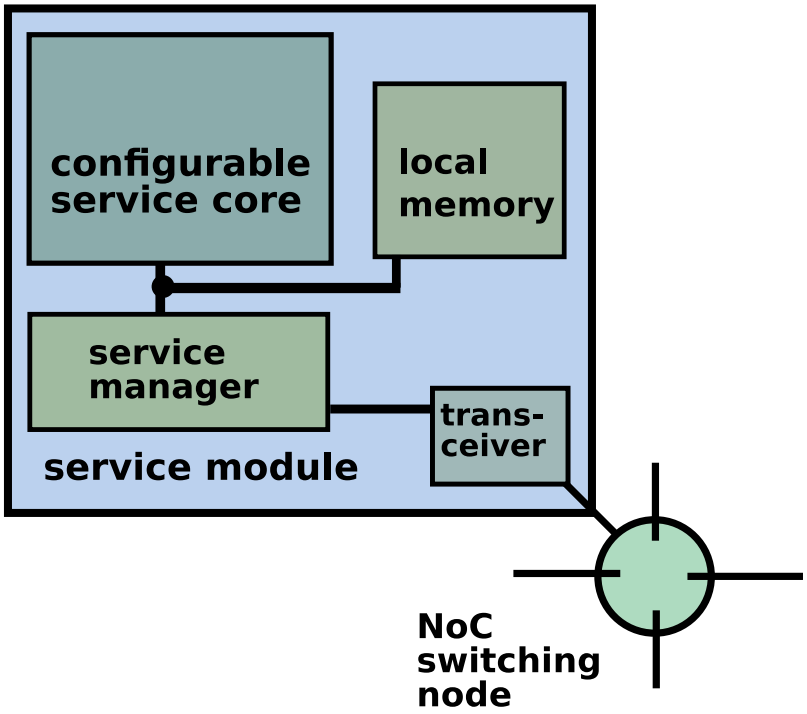
Gannet architecture

Gannet





Gannet system operation

- The Gannet machine is a distributed computing system where every computational node **consumes packets** and **produces packets** and can store state information between transactions.
- We denote a Gannet packet as $p(Type, To, Ret, Id; Payload)$
- The semantics of a Gannet **service** (computational node) can be described in terms of
  - the **task code**
  - the internal state
  - the **result packet(s)** produced by the task

Gannet system operation

1. Service S_i receives a **code** packet $p(Code, S_i, S_j, R_{task}; task)$ where $task = (S_i\ a_1 ... a_n)$. The task is stored with reference R_{task}. Service S_i is in $state_i$.
2. Service S_i receives a task **reference** packet $p(Ref, S_i, S_j, R_{id}; R_{task})$
3. The service activates the task referenced by R_{task}: $(S_i\ a_1 ... a_n)$. This results in evaluation of the arguments $a_1 .. a_n$:
4. The service produces a result packet $p(Type_i, S_j, S_i, R_{id}; Result_i)$ and the state changes to $state_i{}'$.
5. This packet is sent to S_j where $Result_i$ is stored in a location referenced by R_{id}.

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Gannet system operation

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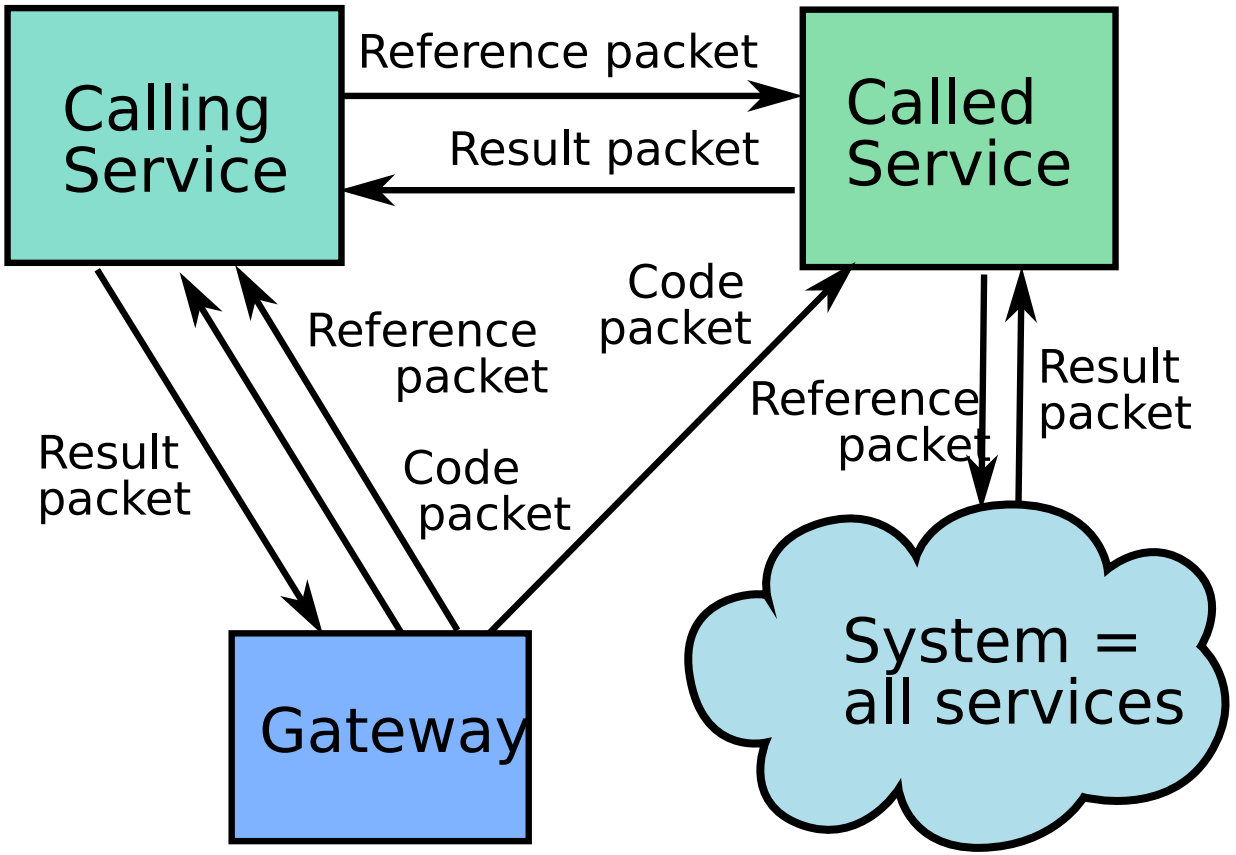

Control services in Gannet

- Any run-time reconfigurable system requires **control constructs** to be effective.
- In Gannet, these constructs (if/then, functions, blocks, variables, ...) are provided by **services**.
- Such **control services** can be efficiently implemented on an embedded microcontroller.
- Interleaving the services provided by the HW cores with control services can cause bottleneck due to memory bandwidth.

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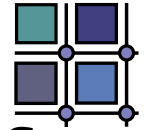
Control services in Gannet



- Ideally, the microcontroller would only exchange control information with the cores.
  - technically not impossible to realise using compiled code but would require
    - a language with functional characteristics (no side-effects, undetermined execution order, laziness, concurrency)
    - access to absolute memory addresses of the data structures
  - program would need to contain a JIT compiler to create bytecode for the service managers at run time.

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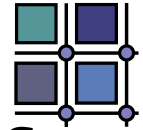
The Gannet Virtual Machine



- A Virtual Machine (VM) which interacts with the hardware service managers:
  - software implementation of the service managers, control service cores and a 'virtual NoC'
  - small, portable C++ application
  - runs byte-compiled programs in the Gannet language
  - same bytecode used by VM and HW

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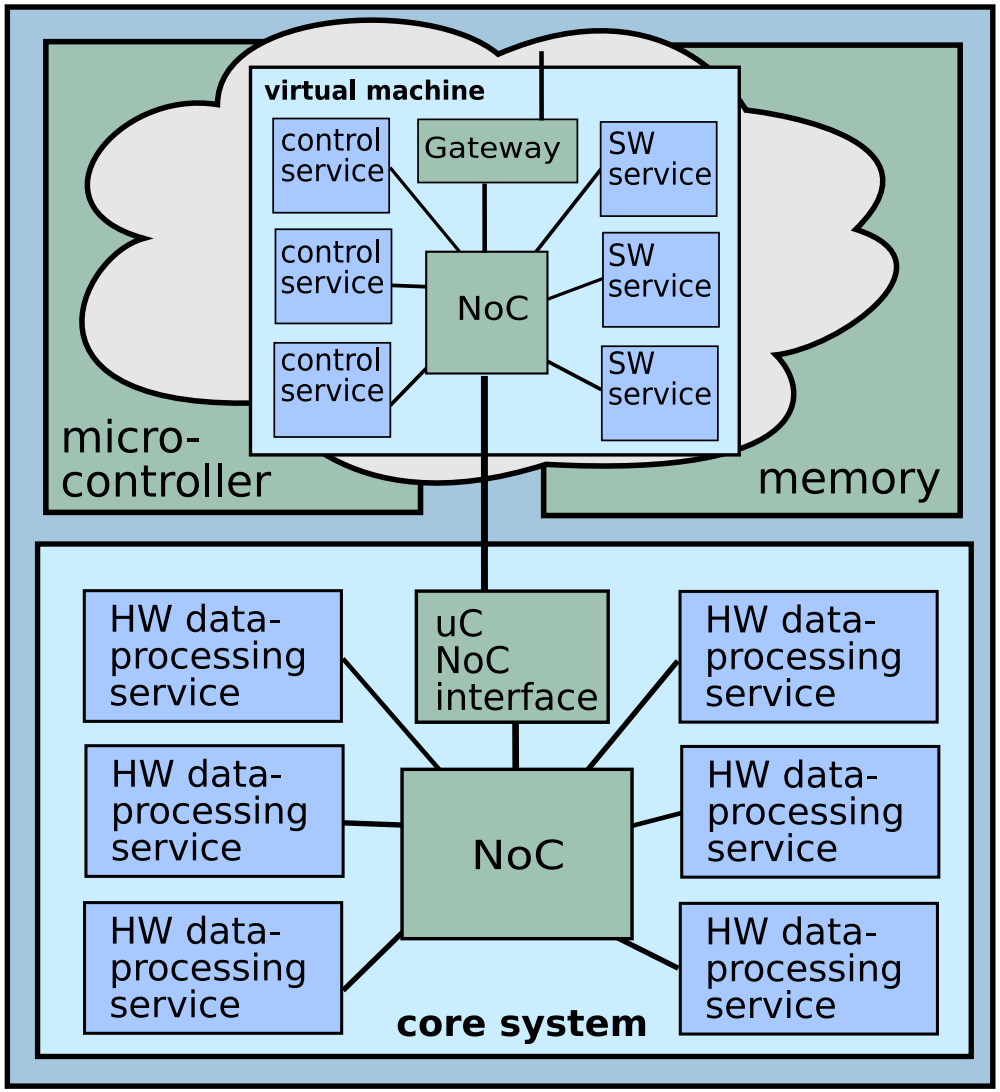
The Gannet system

Gannet



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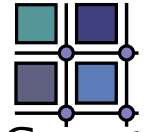
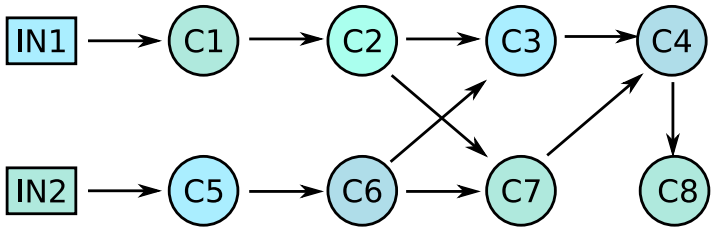
Gannet language



- The “assembly” language to program the Gannet system
- Intended as compilation target, not HLL
- A functional language, every service is mapped to an opaque function
- Gannet is a distributed machine for running this language
- Service = service manager + service core
- Service cores can be implemented in HW or SW

Gannet language syntax

- Previous example in S-expressions syntax:




```
(S8 (S4
        (S3
           (S2 (S1 IN1))
           (S6 (S5 IN2))
        )
        (S7
           (S6 (S5 IN2))
           (S2 (S1 IN1))
        )))
```

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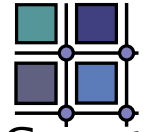
Gannet language syntax



- Example with control services (factorial):

```
(let
    (assign 'fact
        (lambda 'n 'a 'f
          '(if (< n '2)
            'n
            '(apply f (- n '1) (* a n) 'f)
          )))
    (apply fact '4 '1 'fact)
)
```

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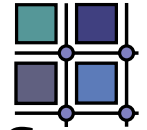
Gannet language properties



- Some key properties of the Gannet language:
  - the evaluation order is unspecified
  - eager by default but lazy evaluation is possible
  - no side effects across services
  - updates of variables are atomic (no race conditions)
- These properties
  - make the language fully concurrent (maximise parallelism)
  - and enable separation of control flow from data flow

Gannet language properties

- **Unspecified execution order:**
  - In a given function call it is not possible to predict the evaluation order of the arguments.
  - In practice, all arguments are evaluated in parallel; call blocks until all arguments are ready.

```
(let
     (assign 'a (S1 ...))
     (assign 'b (S2 ...))
     (S3 ... b ...
         (S4 ... a ...)... )
)
```

Gannet language properties

- **Lazy evaluation:**
  - By default, Gannet is **eager**, i.e. it always evaluates all arguments before passing them on to the service core.
  - It should be possible to evaluate arguments at need ("**lazy**").
  - Laziness is expressed by prefixing an expression or symbol with a single quote:

```
(assign 'a (S1 ...))
```

  - Quoting causes the evaluation of the symbol a to **deferred** to the service core.

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Language properties

Gannet

- **No side effects across services:**
  - A call to a given service should not result in a modification of the state of the rest of the system.
- **Updates of variables are atomic:**
  - No race conditions if several services simultaneously try to modify shared data.
  - The service manager processes all task requests in FIFO order.
  - Not possible to update an unassigned variable.

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Deferred evaluation and result redirection

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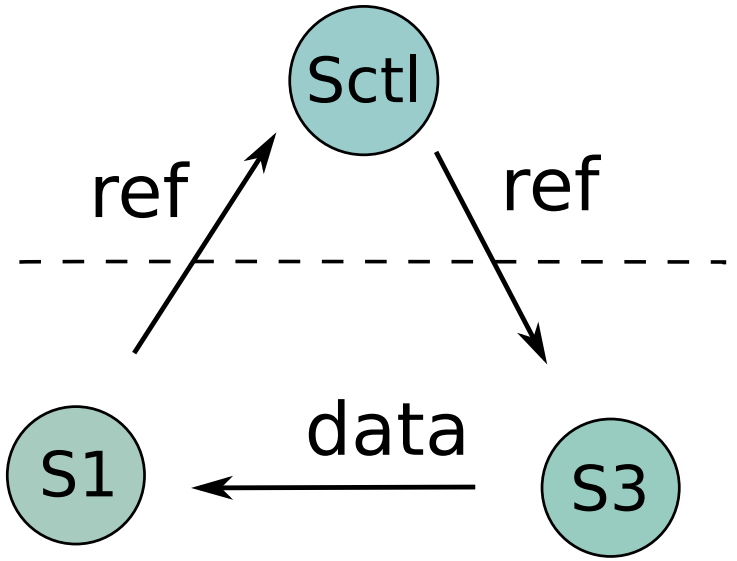
The mechanism for separation of control and data flows: **deferred evaluation** and **redirection:**

```
(S1
   (Sctl
        '(S3 ...)
        ...
   )
   ...
)
```



S_1 sends $p(Ref, S_{ctl}, S_1, R'_1; R_{ctl})$; S_{ctl} sends $p(Ref, S_3, S_1, R'_1; R_3)$

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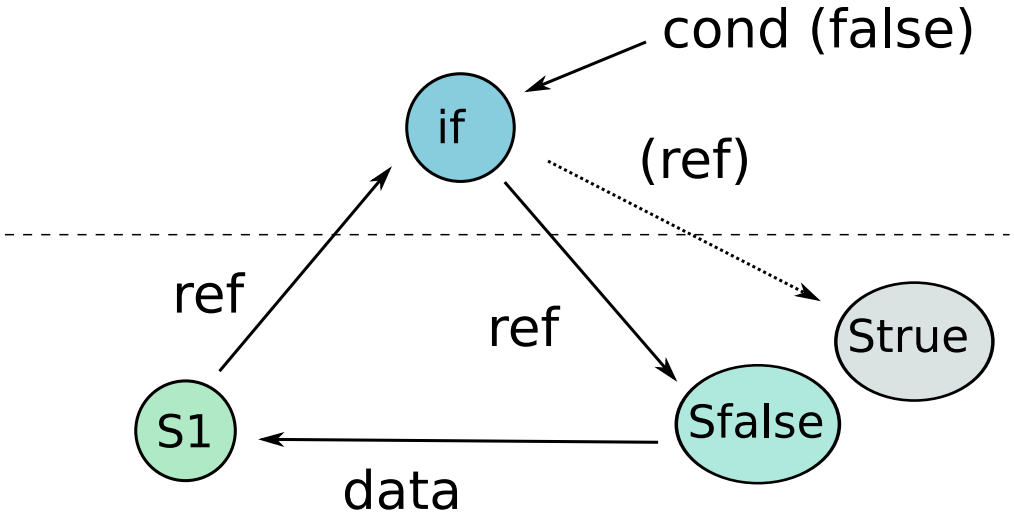
Conditional branching

Gannet

```
(S1
   (if cond
      '(Strue ...)
      '(Sfalse ...)
    )
    ...
)
```



S_{if} sends $p(Ref, S_{false}, S_1, R'_1; R_{false})$

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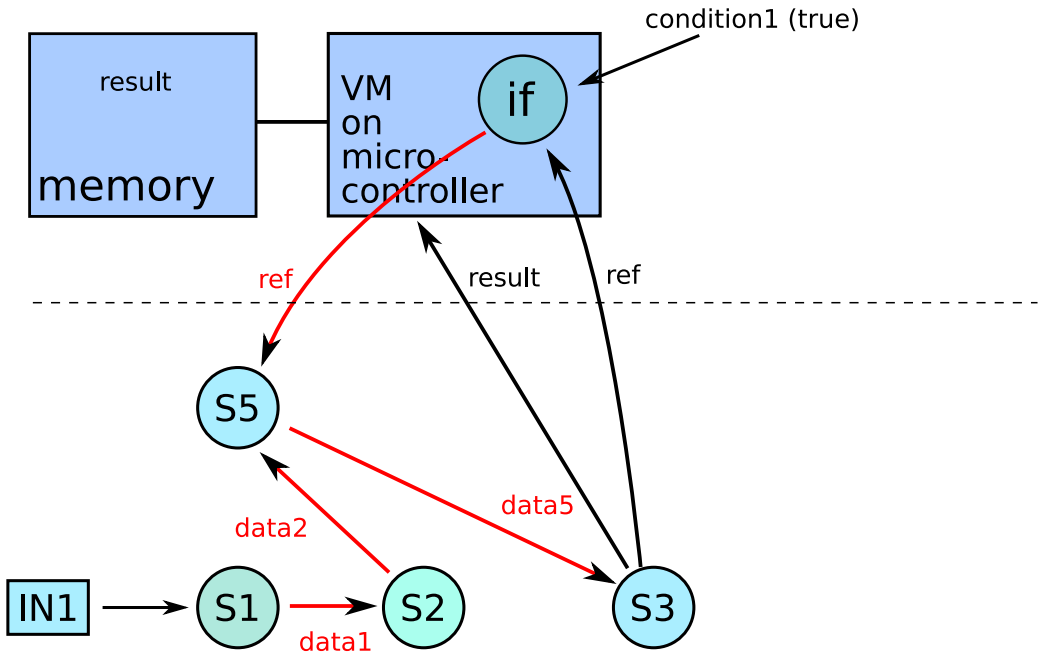
Conditional branching

Gannet

- Revisiting the earlier example:

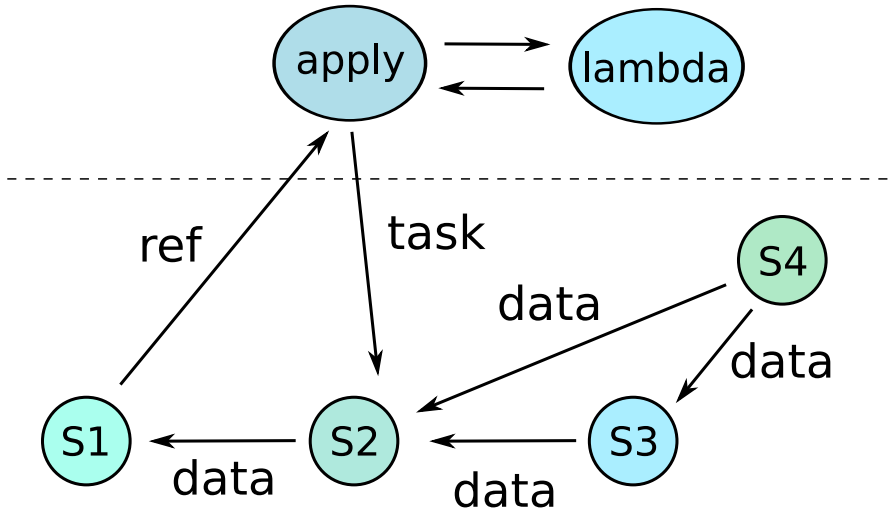
```
(S3
   (if condition1
     '(S5 (S2 (S1 IN1)))
     '(S2 (S5 (s1 IN1)))
    )
)
```



S_{if} sends $p(Ref, S_5, S_3, R'_3; R_5)$

Function definition and application


```
(S1
   (apply
      (lambda 'x
         '(S2 (S3 ... x ...) ... x ...)
      )
      '(S4 ...)
   )
   ...
)
```

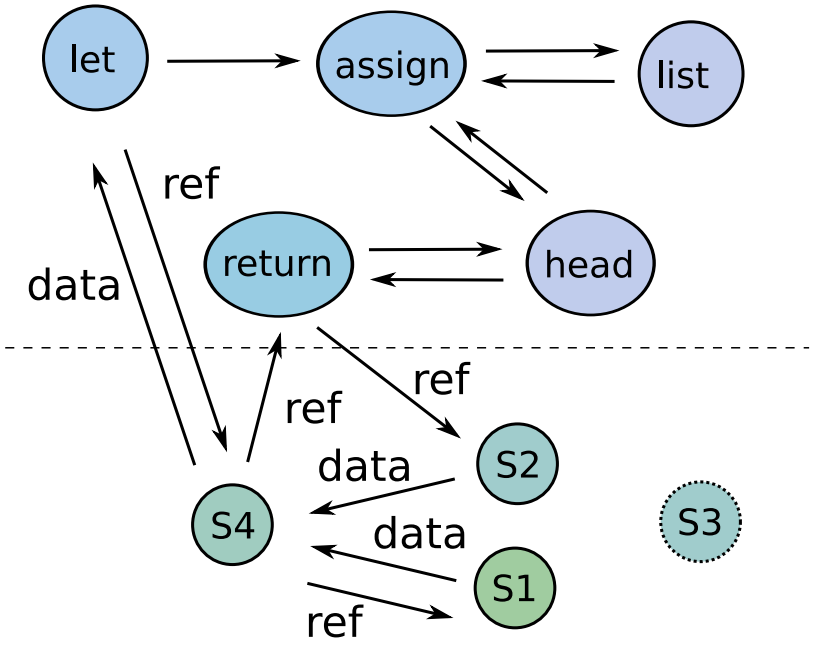


$$S_1((\lambda x \rightarrow S_2(S_3(\ldots,x,\ldots),\ldots,x,\ldots))S_4(\ldots),\ldots)$$

Lists

- `list`: list constructor
- `head`: first element of the list
- `return`: unquotes its argument

```
(let
    (assign 'l (list '(S2 ...) '(S3 ...)))
    (S4 (return (head l)) (S1 ...))
)
```



Conclusion

- Gannet: a service-based SoC architecture for high-level design of reconfigurable heterogeneous multi-core SoCs.
- Alleviate bottleneck resulting from memory bandwidth limitation:

  mechanism for the **separation of control flow and data flow** based on **deferred evaluation** and **packet redirection**.
- Gannet system
  - provides full control over data paths in multi-core SoC;
  - provides full concurrency;
  - ensures that data can flow directly between the cores.

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Status

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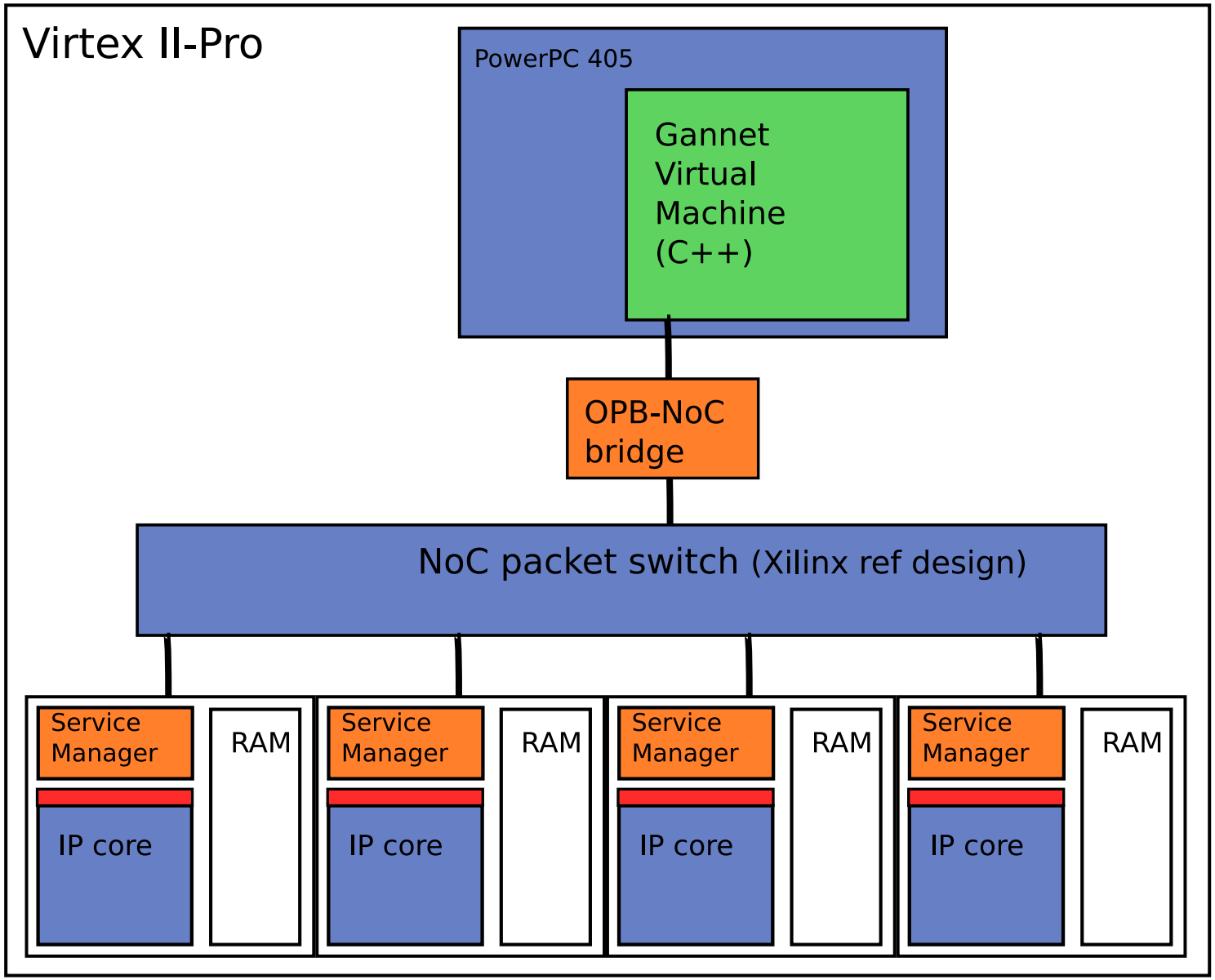

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Status

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