Gannet: a functional task description language for a service-based SoC architecture

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Overview

Gannet

- What is a Gannet service-based System-on-Chip?
- How does it work? Gannet task descriptions
- The need for language constructs
- Language services by example
- Grammar and operational semantics
- Conclusion

What is Gannet?

A distributed System-on-Chip (SoC) architecture

- a collection of processing cores (HW/SW)
- each core offers a a specific **service**
- all services are **fully connected** over an on-chip network (NoC)
- all information is transfered as **packets** over the NoC

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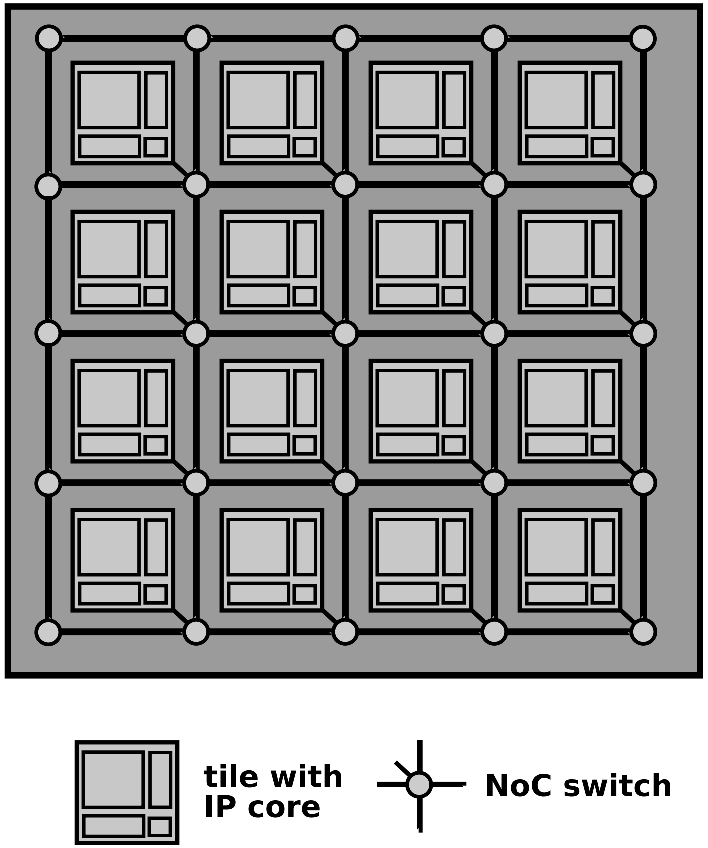
What is Gannet?

Gannet

A distributed System-on-Chip (SoC) architecture



What is Gannet?

A functional machine language

- conceptually: an intermediate language, comparable to assembly language.
- syntactically and semantically: a pure functional language, similar to Scheme.
- the Gannet SoC architecture can be considered as a computing platform, a ”machine” to run the Gannet language.

Why Gannet?

- tomorrow's SoC's will be **very big** (10^{10}logic gates)
  - traditional bus-style interconnect causes a bottleneck:
    - Synchronisation over large distances is impossible
    - Fixed point-to-point result in huge wire overhead
  - **on-chip networks** provide a solution
    - globally asynchronous/locally synchronous
    - flexible connectivity
- design reuse is essential => IP ("Intellectual Property") cores
- IP cores are highly complex, self-contained units
- treating such blocks as **services** is a logical abstraction

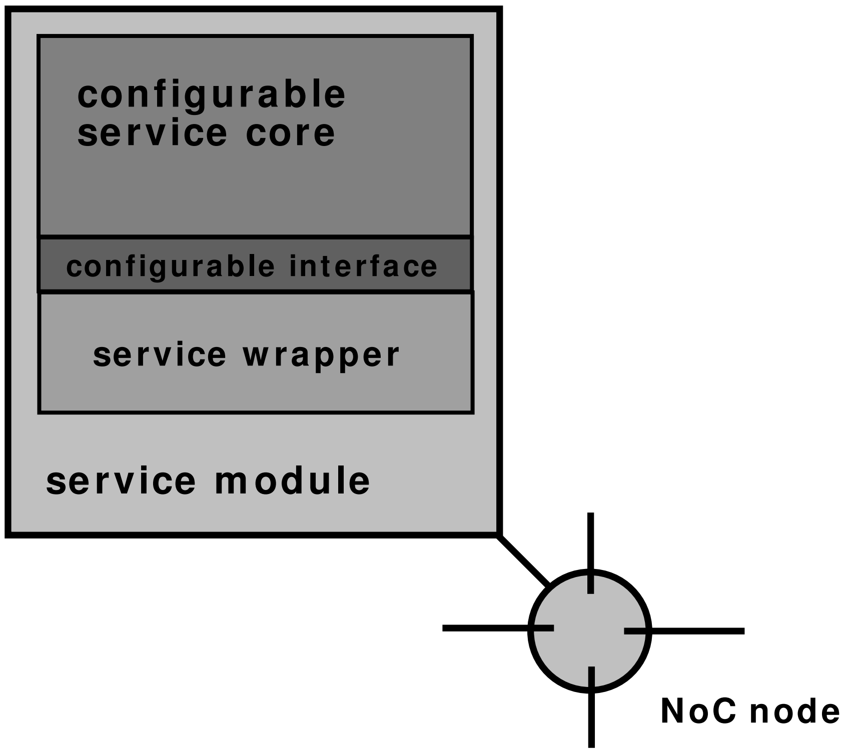
How does a Gannet SoC work?

The services collaborate in a demand-driven dataflow fashion:

- **data** enter the system
- to be processed by **services**
- the **results** of which are, like the data, processed by services
- this process evolves according to a predefined but configurable **task**
- the **description** of such a task is a Gannet **program**

Managing the services

- to manage the flow of **data** and **task descriptions** between the **heterogenous service cores**, every core interfaces with the system through a **service manager**



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Gannet's service manager

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- the task description is a list of **symbols** representing either **data** or **services**
- essentially, the service manager uses two rules to evaluate the task description:
  - Data $\Rightarrow$ request
  - Service $\Rightarrow$ delegate
- it does the bookkeeping of all pending subtasks and the status of each of their arguments
- the service cores are task-agnostic

Gannet Task Description

- Suppose the system merges a number of audio files after having applied some processing to each file. E.g.:
  - Apply filtering with a given spectrum to the first file
  - Change the level of the second file and shift the wave a few seconds to synchronise with the first file
  - Merge both files

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Gannet Task Description

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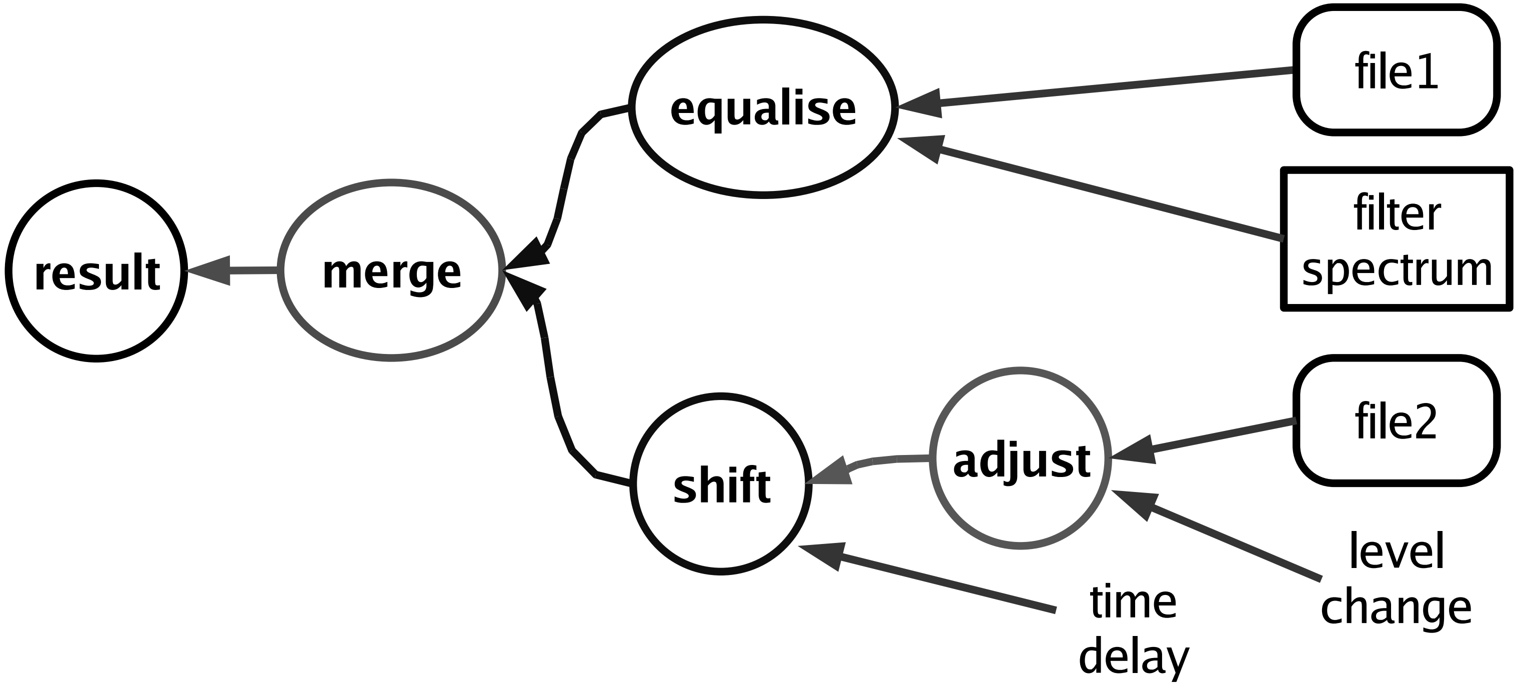
Example task: a system to process audio files.



Syntax

- Human-readable task description format: S-expressions
- EBNF:
  - *expression* ::= (*service_symbol* *argument_symbol*+)
  - *argument_symbol* ::= *expression* | *data_symbol*

Example:

```
(merge
    (shift time_delay
        (adjust level_change file2))
    (equalise filter_spectrum file1))
```

Symbols

- Symbol has 5 fields: Kind, Task, Subtask, Name, Count
- In the current prototype, a symbol is 64 bits long

Example in symbols:

```
S 1 9 merge        9
S 1 5 shift        5
D 1 1 time_delay    1
S 1 3 adjust       3
D 1 1 level_change  1
```

...

The need for a proper language

The Gannet task description approach

- allows in principle to describe arbitrary complex tasks
- but has severe limitations:
  - memory requirements
  - limited parallelism – no fan-in
  - no conditional branching
  - no loop constructs – program size

Solution: Adding language services

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Reducing memory utilisation

- Lexically scoped variables reduce memory utilisation

```
(group
    (assign 'v1 (group
        (assign 'v1 (S d11 d12))
        (assign 'v2 (S d21 d22))
        (S v1 v2))
    (assign 'v2 (S d41 d42))
    (S v1 v2 ))
```

- The `assign` service binds the result of a service call.
- The `group` service is creates the scope.

The Gannet Quote

- The quote ’ indicates to the service manager that the following argument symbols must not be requested but **passed on as-is** to the service core
- Is implemented as a separate symbol

```
(S1 ’d1)
```

Symbols:

```
S 1 1 S1 3
Q 1 1 ’ 2
D 1 1 d1 1
```

Parallelism

- Service cores can produce multiple results.
- But a service can only return a single value.

List values: **list** service

```
(group
    (assign 'l1 (S1 d1 d2))
    (assign 'l2 (list
        (S2 (head l1))
        (S3 (head (tail l1)))
        (concat l1 (list d4)))
    (S4 (head l1) (head l2)))
```

Conditional branching

- Depending on some condition, subtasks might be delegated to different services.

Conditional branching: **`if`** service

```
(if (S_test_condition d1) (S1 d1) (S2 d1))
(if (S_test_condition d1) '(S1 d1) '(S2 d1))
```

- Quoting causes lazy evaluation, but is optional

Program size

- Without iterative or recursive constructs and subroutines or functions, a task description could become very large

Lambda functions and recursion: **`lambda`** and **`apply`** services

```
(group
    (assign 'f (lambda 'x 'y '(* x y))
    (apply f d1 d2)
)
```

Operational semantics

- For a Gannet language program in the context of the Gannet machine
- Independent on the syntax introduced above
- Context-sensitive reduction semantics (Felleisen)
- Evaluation of a service expression has two distinct, atomic stages:
  - **marshalling** stage (M)
  - **processing** stage (P)

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Grammar

- Symbols and Symbol lists ($\langle \ldots \rangle$: symbol list boundary)

$$symbol\text{-}list ::= \langle (symbol \mid symbol\text{-}list) + \rangle$$

- Expressions

$$\begin{aligned} expression ::= & \; variable\text{-}symbol \\ & \mid \; service\text{-}expression \\ & \mid \; quoted\text{-}expression \end{aligned}$$

$$service\text{-}expression ::= \langle service\text{-}symbol \;\; expression + \rangle$$

$$\begin{aligned} quoted\text{-}expression ::= & \langle quote\text{-}symbol \;\; expression + \rangle \\ & \mid \langle quote\text{-}symbol \;\; argument\text{-}symbol \rangle \end{aligned}$$

Grammar

- Language service expressions

$$group\text{-}expr ::= \langle \textbf{group}\ assign\text{-}expr+\ \ expr+ \rangle$$
$$assign\text{-}expr ::= \langle \textbf{assign}\ quote\text{-}symbol\ variable\text{-}symbol\ \ expr \rangle$$

$$lambda\text{-}expr ::= \langle \textbf{lambda}\ \ quoted\text{-}arg\text{-}list\ \ quoted\text{-}expr \rangle$$
$$quoted\text{-}arg\text{-}list ::= \langle quote\text{-}symbol\ argument\text{-}symbol \rangle *$$
$$apply\text{-}expr ::= \langle \textbf{apply}\ \ (lambda\text{-}expr | variable\text{-}symbol)\ \ expr+ \rangle$$

Operational semantics

- Shorthand notation

$$expression : e$$

$$quoted - expression : qe$$

$$service - expression : se$$

$$service - symbol : s$$

$$variable - symbol : v$$

$$argument - symbol : x$$

$$number - symbol : n$$

$$value : w$$

Operational semantics

- Evaluation context

$$C ::= [\,] \mid \langle s \ldots C \ldots \rangle$$

- Store
  - The Gannet machine does not have global, shared memory; every service has its own local memory, with read-only access for the other services
  - The $\mathbf{store}()$ concept must be contextualised (subscript to indicate context of store)

Non-language services

- Delegate Service

$$C[\langle s \;...se_1...\rangle] \rightarrow^M C[s...w_1...]$$

- Request Data

$$(store_{data}(...(d_1 w_1)...)\; C[\langle s \;...d_1...\rangle])$$

$$\rightarrow^M \;(store_{data}(...(d_1 w_1)...)\; C[s...w_1...])$$

- Store Quoted expression

$$C[\langle s \;...qe_1...\rangle] \rightarrow^M C[s...e_1...]$$

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Language services

- Variables

$$(\mathbf{store}_{\mathbf{assign}}(\ldots)\ C[\langle \mathbf{assign}\ qv\ e\rangle])$$

$$\rightarrow^{M} (\mathbf{store}_{\mathbf{assign}}(\ldots)\ C[\langle \mathbf{assign}\ v\ w\rangle])$$

$$\rightarrow^{P} \quad (\mathbf{store}_{\mathbf{assign}}(\ldots(v\ w)\ldots)\ C[\#t])$$

- Grouping

$$(\mathbf{store}_{\mathbf{assign}}(\ldots)\ C[\langle \mathbf{group}\ \ldots\langle \mathbf{assign}\ qv_i\ e_i\rangle\ldots\ e\rangle])$$

$$\rightarrow^{M} \quad (\mathbf{store}_{\mathbf{assign}}(\ldots(v_i\ w_i)\ldots)\ C[\langle \mathbf{group}\ \ldots\#t\ldots\ w\rangle])$$

$$\rightarrow^{P} \qquad (\mathbf{store}_{\mathbf{assign}}(\ldots)\ C[w])$$

Language services

- Function definition and application

$$C[\langle \textbf{lambda}\ qx_1 \ldots qx_i \ldots qx_n\ qe_a\rangle]$$
$$\rightarrow^{M} C[\langle \textbf{lambda}\ x_1 \ldots x_i \ldots x_n\ e_a\rangle]$$
$$\rightarrow^{P}\ C[\langle\ x_1 \ldots x_i \ldots x_n e_a\rangle]$$

- Function definition and application

$$(\textbf{store}_{\textbf{apply}}(\ldots)\ \ C[\langle \textbf{apply}\ \ \langle \textbf{lambda}\ qx_1 \ldots qx_i \ldots qx_n\ qe_a\rangle\ \ e_1 \ldots e_i\ \ldots e_n\rangle]$$
$$\rightarrow^{M}\quad (\textbf{store}_{\textbf{apply}}(\ldots)\ \ C[\langle \textbf{apply}\ \ \langle\ x_1 \ldots x_i \ldots x_n\ e_a\rangle\ \ w_1 \ldots w_i\ \ldots w_n\rangle])$$
$$\rightarrow^{P}\quad (\textbf{store}_{\textbf{apply}}(\ldots(x_1\ w_1)\ldots(x_i\ w_i)\ldots(x_n\ \ w_n))\ \ C[e_a[\ x_i/\ w_i])$$

Conclusion

- Gannet project: facilitate high abstraction-level design of complex SoCs
- Novel **service-based** SoC architecture
- Distributed processing system
- Executes tasks defined in terms of cooperating services
- Functional **task description** language.
- Introducing **language services** to improve system performance.
- Next step: optimising the language to minimise resource utilisation