



HAL
open science

HoCL High level specification of dataflow graphs

Jocelyn Sérot

► **To cite this version:**

Jocelyn Sérot. HoCL High level specification of dataflow graphs. Réunion thématique du GdR ISIS, Nov 2020, Rennes, France. hal-03038307

HAL Id: hal-03038307

<https://uca.hal.science/hal-03038307>

Submitted on 3 Dec 2020

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License

HoCL

High level specification of dataflow graphs

Jocelyn Sérot

Institut Pascal, UMR 6602 U. Clermont-Auvergne / CNRS
IETR, UMR 6164 I. Rennes I / CNRS



GdR ISIS

2020-11-18

Introduction

Question 1

Q :What are the three most things in programming ?

A :

1. abstraction
2. abstraction
3. abstraction

Question 2

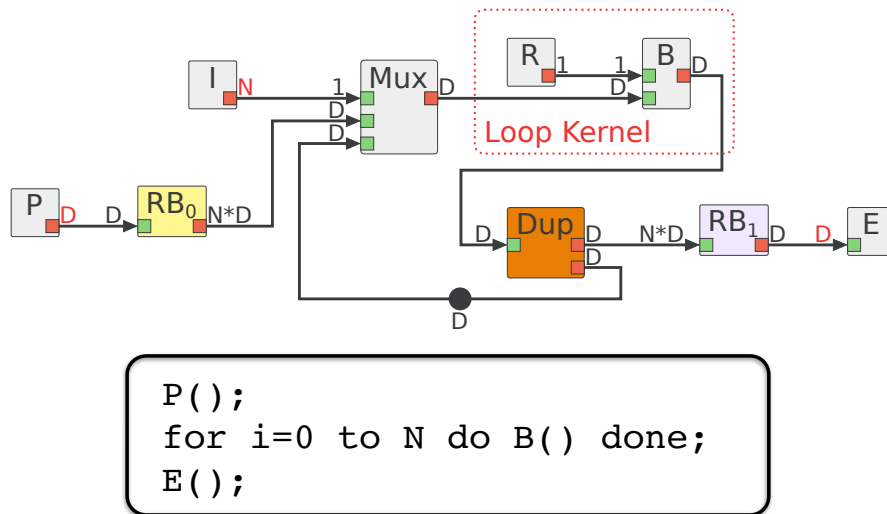
Q : Do dataflow models promote abstraction ?

A : Well, it depends...

EXAMPLE 1

Dataflow formulation of an iterative algorithm in Preesm

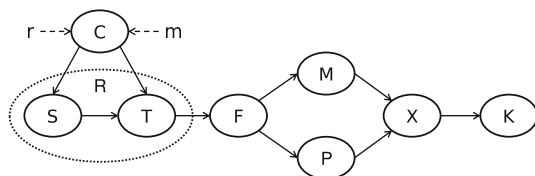
<https://preesm.github.io>



Source : *Extensions and Analysis of Dataflow Models of Computation for Embedded Runtimes.* PhD thesis. F. Arrestier, 2020.

EXAMPLE 2

Dataflow formulation of an RMOD application in DIF (Dataflow Interchange format)



```

CFDF RMOD {
  topology {
    nodes = C, S, T, F, M, P, X, K;
    edges = e1(C, S), e2(C, T), e3(S, T), e4(T, F),
           e5(F, M), e6(F, P), e7(M, X), e8(P, X), e9(X, K);
  }
  actor C {
    name = "mod_ctrl";
    out_r = e1; out_m = e2; /* Assign edges to ports */
  }
  actor S {
    name = "mod_src";
    in_ctrl = e1; out_data = e3;
    mode_count = 3;
  }
  actor T {
    name = "mod_lut";
    in_ctrl = e1; in_bits = e3; out_symbol = e4;
    mode_count = 4;
  }
  /* Other actor definitions */
  /* ... */
}

```

Source : *The DSPCAD Framework for Modeling and Synthesis of Signal Processing Systems.* Shuoxin Lin, Yanzhou Liu, Kyunghun Lee, Lin Li, William Plishker, and Shuvra S. Bhattacharyya, 2017.

Motivations

- Simplify the **specification** of large and complex **dataflow graphs**
- Independently of the underlying dataflow **model of computation**
 - pure **coordination language** (..CL = *Coordination Language*)
- Support for **hierarchical** and **parameterized** graphs
- Independently of the **target implementation** platform (software, hardware, mixed, ...)
- Support for mixed-style descriptions (structural or **functional**)

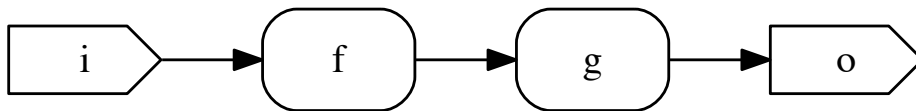
This presentation

- Informal presentation of the language by means of small examples
- Technical details such as typing, semantics, etc. deliberately omitted
 - <https://github.com/jserot/hocl>

Core features



Example 1



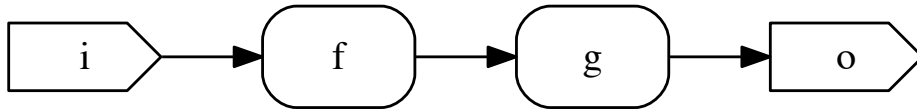
```
node f
  in (i: int) out(o: int);

node g
  in (i: int) out(o: int);

graph top
  in (i: int)
  out (o: int)
  struct
    wire w: int
    box n1: f(i)(w)
    box n2: g(w)(o)
  end;
```

- This defines a **graph top**, with input *i* and output *o*.
- This graph is built from two **boxes**, *n1* and *n2*, linked by a **wire** *w*
- Boxes and wires are *typed*
- Each box is an *instance* of a **node** (*f* and *g* resp.)
- Nodes *f* and *g* are here defined as opaque **actors** (black boxes)
- The **graph top** is here defined **structurally**

Example 1



```
node f
  in (i: int)
  out(o: int);

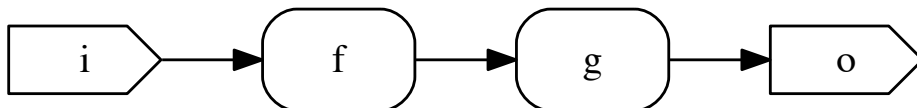
node g
  in (i: int)
  out(o: int);

graph top
  in (i: int)
  out (o: int)
  fun
    val o = g (f i)
  end;
```

- This is an alternative description of graph top using a **functional** style
- Nodes are interpreted as *functions* and the graph is described using function application
 - applying function f to value x (here denoted as $f\ x$) builds a node by instantiating actor f and connecting the wire representing the value x to its input
- An actor with m inputs $e_1:t_1, \dots, e_m:t_m$ and n outputs $s_1:t'_1, \dots, s_n:t'_n$ is interpreted as a (curried) function of type

$$e_1:t_1 \rightarrow \dots \rightarrow e_m:t_m \rightarrow t'_1 * \dots * t'_n$$

Example 1



```
node f
  in (i: int)
  out(o: int);

node g
  in (i: int)
  out(o: int);

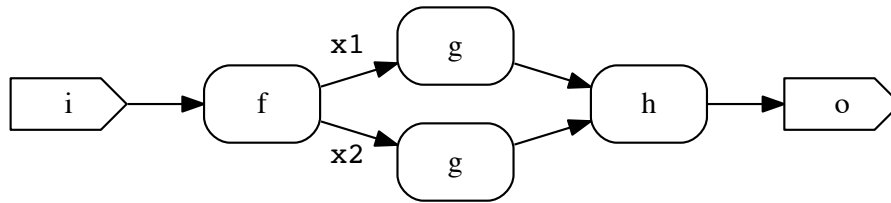
graph top
  in (i: int)
  out (o: int)
  fun
    val o = i |> f |> g
  end;
```

- Another functional formulation using the *reverse application operator* $|>$:

$$x\ |>\ f = f\ x$$

Example 2

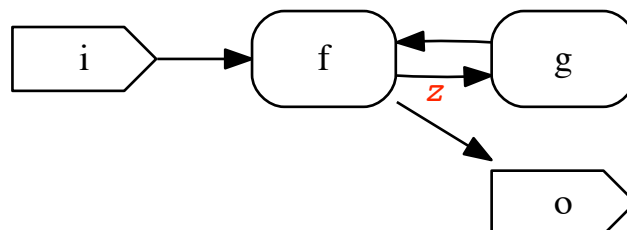
A slightly more complex graph



```
node f in (i: int) out (o1: int, o2:int);  
node g in (i: int) out (o: int);  
node h in (i1: int, i2:int) out (o:int);
```

```
graph top  
  in (i: int)  
  out (o: int)  
fun  
  val (x1,x2) = f i  
  val o = h (g x1) (g x2)  
end;
```

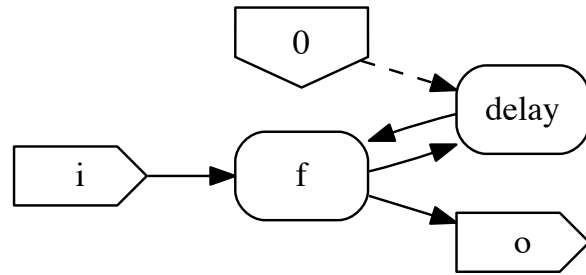
Cycles and recursive wiring



```
node f in (i1: t1, i2: t2) out (o1: t4, o2: t3);  
node g in (i: t3) out (o: t2);
```

```
graph top  
  in (i: t1) out (o: t4)  
fun  
  val rec (o,z) = f i (g z)  
end;
```


Delayed cycles



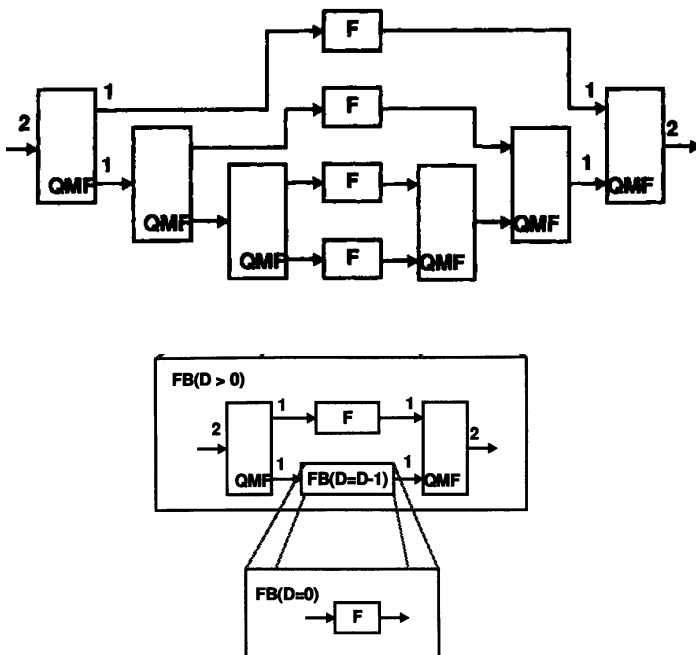
```
graph top
  in (i: int) out (o: int)
  fun
    val rec (o,z) = f (i, delay '0' z)
  end;
```

```
graph top
  in (i: int) out (o: int)
  struct
    wire w1, w2: int
    box n1: f(i,w1)(o,w2)
    box n2: delay('0',w2)(w1)
  end;
```

- Delays are required to avoid deadlock when **simulating** the graph (they provide the initial token(s) on the feedback edge(s))
- The special actor *delay* is predefined (and interpreted specifically by the various backends)
 - the actor *parameter* ('0', here) specifies the initial value)
- Using type or application specific delay actors is also possible

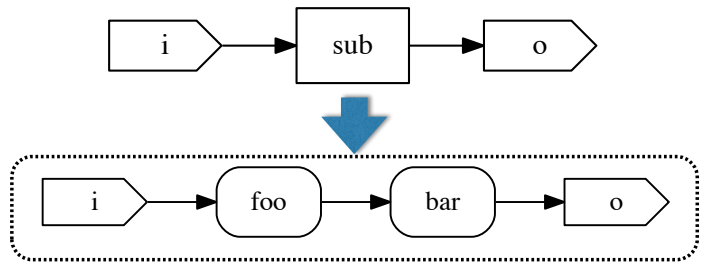
Recursive graphs

Example (from [Lee and Parks, 1995])



```
node f
  in (i: t)
  out (o: t);
node qmf
  in (i: t)
  out (o1: t, o2: t);
graph top
  in (i: t)
  out (o: t)
  fun
    val rec fb d x =
      if d = 0 then f x
      else
        let x1,x2 = qmf x in
          qmf (f x1)
              (fb (d-1) x2)
    val o = fb 3 i
  end;
```

Hierarchical graphs



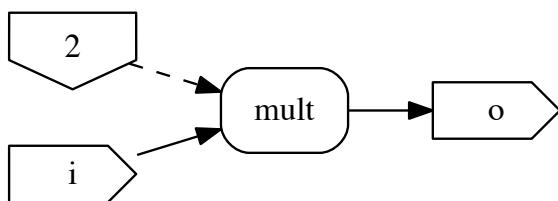
```
node foo in (i: t) out (o: t);
node bar in (e: t) out (s: t);

node sub in (i: t) out (o: t)
fun
  val o = i |> foo |> bar
end;

graph top in (i: t) out (o: t)
fun
  val o = i |> sub
end;
```

- Nodes can be described as (sub)graphs (either structurally or functionally), giving rise to **hierarchical** graphs
- Node with no description are interpreted as opaque actors (« blackboxes »)
- **Toplevel** graphs are identified with the `graph` keyword

Parameters



```
node mult
  in (k: int param, i: int)
  out (o: int);

graph top
  in (i: int) out (o: int)
  fun
    val o = i |> mult '2'
  end;
```

- Parameters are used to *configure* (*specialize*) nodes
- Parameters are distinguished from data by their type :
 - `t param` is the type of a parameter having itself type `t`
- In functional descriptions, this allows specifying their value using **partial application** of the corresponding function

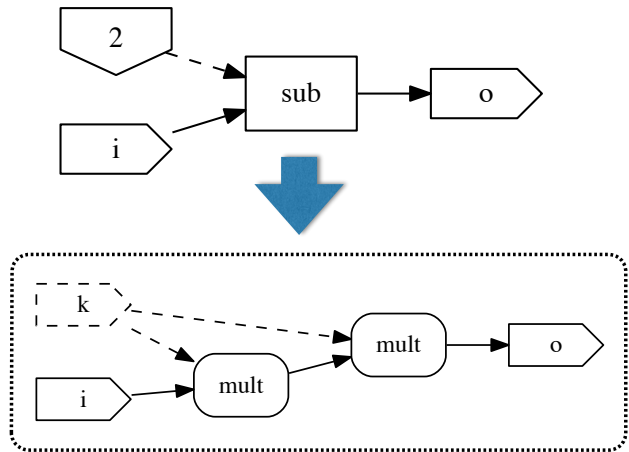
Parameter passing

- Parameters can be passed from one hierarchy level to a nested one

```

node sub
  in (k: int param, i: int)
  out (o: int)
  fun
    val o =
      i |> mult k |> mult k
  end;

graph top
  in (i: int) out (o: int)
  fun
    val o = i |> sub '2'
  end;
  
```

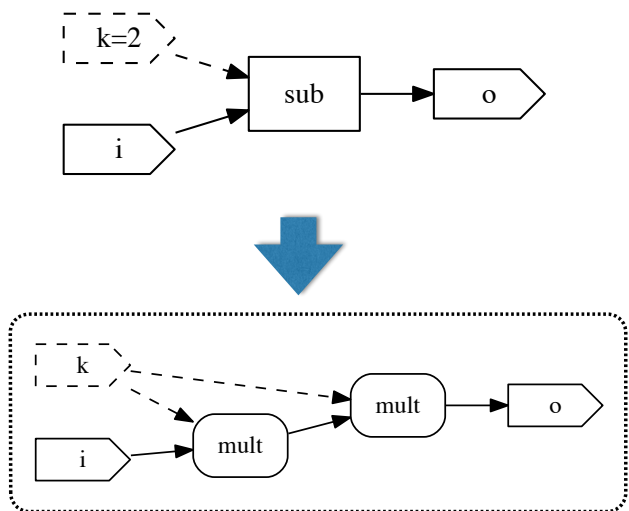


Parameter passing

```

node sub
  in (k: int param, i: int)
  out (o: int)
  fun
    val o =
      i |> mult k |> mult k
  end;

graph top
  in (k: int param=2, i: int)
  out (o: int)
  fun
    val o = i |> sub k
  end;
  
```

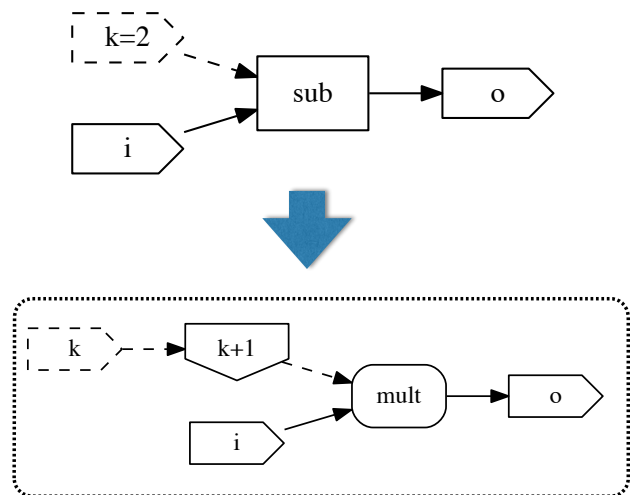


- The value of the toplevel parameters can be defined in the corresponding graph interface

Parameter dependencies

```
node sub
  in (k: int param, i: int)
  out (o: int)
  fun
    val o =
      i |> mult 'k+1'
  end;

graph top
  in (k: int param=2, i: int)
  out (o: int)
  fun
    val o = i |> sub k
  end;
```



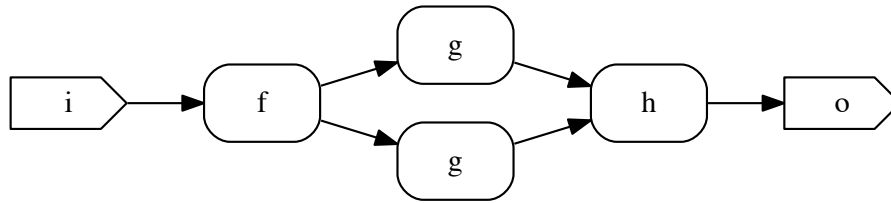
- The value of some parameters can depend on that of other parameters, defined at the same or at higher level(s) in the graph hierarchy
- Dependencies between parameter values create a tree in graph, which is “orthogonal” to the data flow

Higher order features

Ho..



Wiring functions

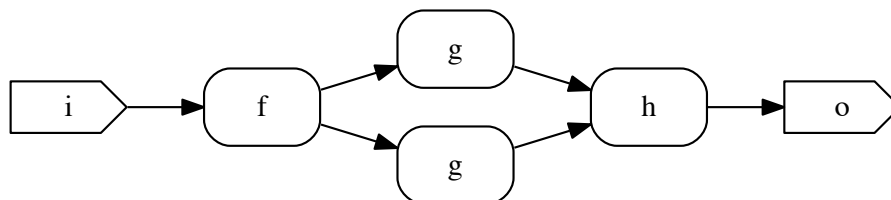


Another formulation :

```
graph top
  in (i: int)
  out (o: int)
  fun
    val body x =
      let (x1,x2) = f x in
      h (g x1) (g x2)
    val o = body i
  end;
```

- **body** is a **wiring function** : it encapsulates the wiring pattern of the encoded graph
- The definition of body makes use of a local definition (*let .. in*)
- The top graph is built by simply applying this function
- Wiring functions can be defined within a (sub)graph (local scope) or globally

Higher order wiring functions

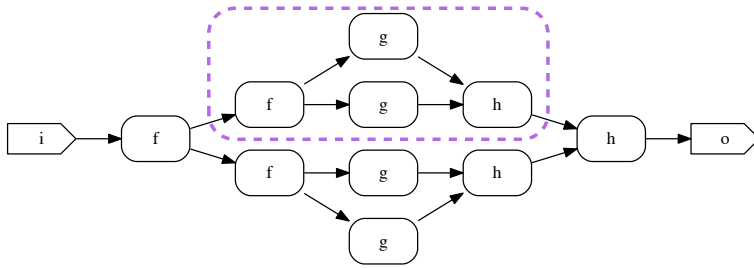


Pushing the abstraction a bit further :

```
graph top
  in (i: int)
  out (o: int)
  fun
    val diamond left middle right x =
      let (x1,x2) = left x in
      right (middle x1) (middle x2)
    val o = diamond f g h i
  end;
```

- The **diamond** function abstracts further the definition of **body**, by taking as parameters the actors to be instantiated to build the defined graph
- The graph *top* is built by supplying the actual actors (*f*, *g* and *h*) as arguments to **diamond**.
- **diamond** is an **higher-order wiring function** (HOWF)

Higher order wiring functions



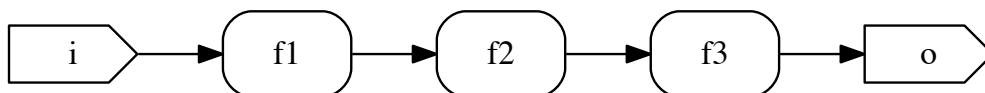
```
graph top
  in (i: int) out (o: int)
  fun
    val diamond l m r x = ...
    val sub = diamond f g h
    val o = diamond f sub h i
  end;
```

```
graph top
  in (i: int) out (o: int)
  struct
    wire w1,w2,w3,w4,
        w5,w6,w7,w8,
        w9,w10,w11,w12:int
    box f1: f(i)(w1,w2)
    box f2: f(w1)(w3,w4)
    box f3: f(w2)(w5,w6)
    box g1: g(w3)(w7)
    box g2: g(w4)(w8)
    box g3: g(w5)(w9)
    box g4: g(w6)(w10)
    box h1: h(w7,w8)(w11)
    box h2: h(w9,w10)(w12)
    box h3: h(w11,w12)(o)
  end;
```

- The *diamond* function is here instantiated at two levels :
 - within the *sub* function, to describe the « inner » diamond structure
 - within the definition of the output *o*, to build the toplevel graph structure

« Classic » higher order wiring functions

- Many recurrent **graph patterns** can be **encapsulated** using higher-order wiring functions
- Example :



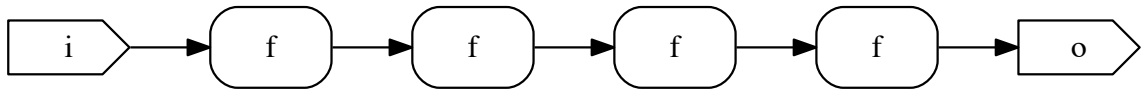
```
graph top
  in (i: int)
  out (o: int)
  fun
    val o = i |> pipe [f1;f2;f3]
  end;
```

where :

```
val rec pipe fs x = match fs with
  [] -> x
  | f::fs' -> pipe fs' (f x);
```

« Classic » higher order wiring functions

- Many recurrent **graph patterns** can be **encapsulated** using higher-order wiring functions
- Example :



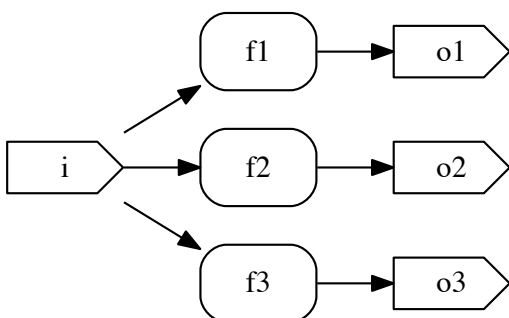
```
graph top
  in (i: int)
  out (o: int)
  fun
    val o = i |> iter 4 f
  end;
```

where :

```
val rec iter n f x =
  if n = 0 then x
  else iter (n-1) f (f x)
```

« Classic » higher order wiring functions

- Many recurrent **graph patterns** can be **encapsulated** using higher-order wiring functions
- Example :



```
graph top
  in (i:int)
  out (o1:int, o2:int, o3:int)
  fun
    val (o1,o2,o3) =
      i |> mapf [f1;f2;f3]
  end;
```

where :

```
val rec mapf fs x = match fs with
  [] -> []
  | f::fs' -> f x :: mapf fs' x;
```

Higher order wiring functions

- Higher order wiring functions
 - promote **abstraction**
 - allow common **graph patterns** to be **encapsulated** for reuse
- In HoCL, they are defined within the language itself
 - the set of available reusable patterns can therefore be freely extended to suit the application domain
 - this is in contrast with existing dataflow-based design tools in which similar abstraction mechanisms rely on a predefined and fixed set of patterns

In practice

Implementation

- Prototype compiler written in OCaml
- Based upon a fully formalized static semantics (natural style)
- Source code available on github (jserot/hocl)
- Two versions
 - a command line compiler
 - a toplevel interpreter
- The CL compiler currently has four backends
 - a .dot backend (for visualizing the DFGs)
 - a DIF backend (for interfacing to DF-based analysis tools)
 - a Preesm backend (for generating code on heterogeneous many-core embedded platforms)
 - a SystemC backend (for simulation under the DDF and SDF MoCs)

Example : using the SystemC backend

- Used to simulate the described DFGs
- Initialisation and per-activation code provided as external C functions
- Automatic generation of FIFOs, delay, broadcast and IO nodes (reading/writing files)

Example

```
node foo
  in (i: int) out (o: int)
actor
  systemc(
    loop_fn="foo",
    incl_file="foo.h",
    src_file="foo.cpp")
end;

graph top
  in (i: int) out (o: int)
  fun
    val o = i |> foo
  end;
```

main.hcl

```
void foo(IN int *i, OUT int *o);
```

foo.h

```
void foo(IN int *i, OUT int *o)
{ *o = *i * 2; }
```

foo.c

```
1 2 3 4 ...
```

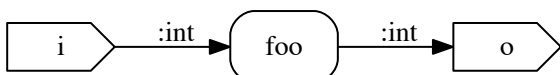
top_i.dat

```
bash> hoclc -systemc main.hcl
# Wrote file systemc/main_top.cpp
# Wrote file systemc/top_gph.h
# Wrote file systemc/foo_act.h
# Wrote file systemc/foo_act.cpp
```

```
bash> cd ./systemc; make
```

```
2 4 6 8 ...
```

top_o.dat



Conclusion

- Another attempt to bring the benefits of functional programming outside its « classical » circle
 - programmers in the DSP field are *not* familiar with concepts such as polymorphic typing and higher order functions
- Drawing of previous experience in a similar context with the CAPH project (<http://dream.ispr-ip.fr/CAPH>)
 - provide interfaces to existing, already used, tools
 - demonstrate practical benefits wrt. this tools
 - introduce disruptive concepts only if it serves a well identified goal

Conclusion

- Work in progress
 - injection of MoC-specific features into specifications
 - design of large scale DSP applications with HoCL for assessing gains if programmer's productivity

Thanks for your (remote) attention