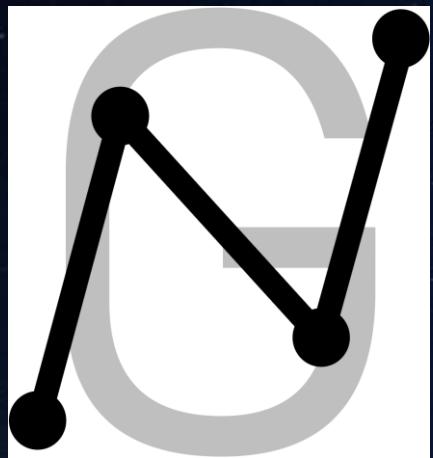


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NanoGraph

A graph interpreter for
DSP/ML stream-based processing



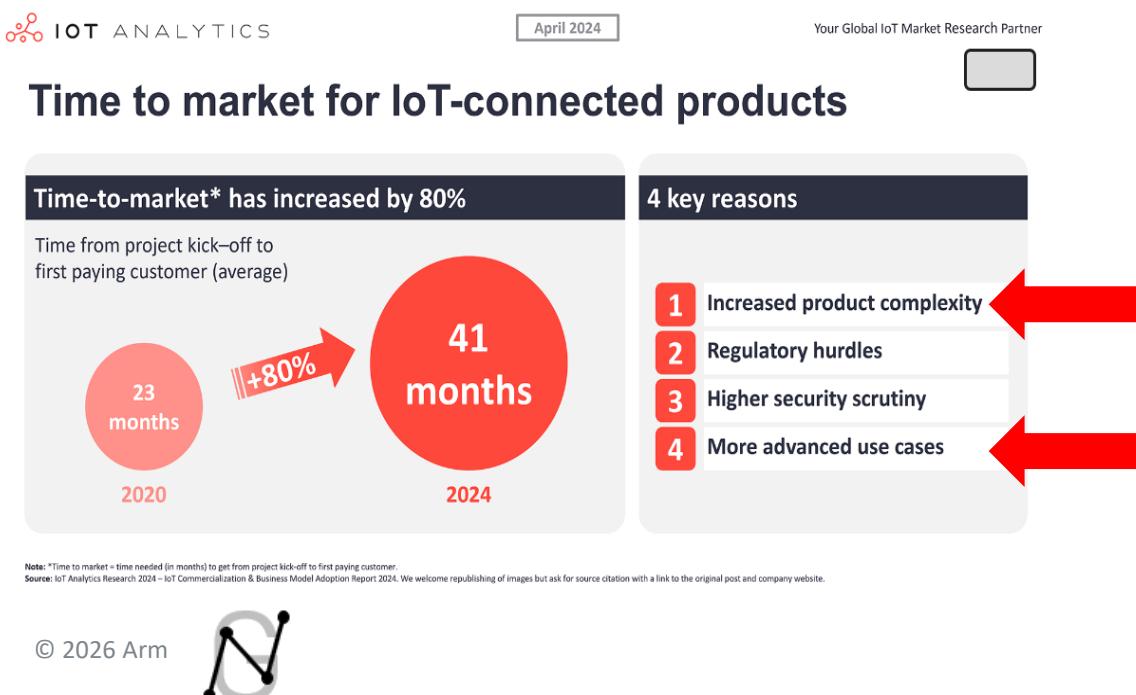
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DSP/ML systems are complex, which slows down time-to-market

Real-world complexity - coming from multiple physical domains - and the complexity of DSP/ML software both contribute to **long development cycles**. To address this:

- The overall problem is broken into smaller, manageable **computing nodes**.
- These nodes are stored in Flash and activated through an **interpreted stream-processing scenario**.
- A **low-code** development model makes it easy to add new nodes as needed.



Splitting the problem, by looking at the users' focus

Silicon vendors

Demonstrate architecture capabilities with micro-kernels

Ensure the software ecosystem can easily migrate to new hardware

Software developers

Want simple development with solid tools and libraries

Need portability and scalable performance for existing code

System integrators

Need access to a wide catalog of applications with acceptable performance

Require strong tools to accelerate time-to-market

Key selling points of NanoGraph

Many pre-installed nodes stored in Flash

Standard interfaces, secured “Stores”
libs : NEON/MVE.. malloc for TCM
Nodes language independent

Graph portability, AI runs locally
Low-code, Fast tuning
Lower the risk of failed FW updates
Self-recovery (drift, warm-boot)

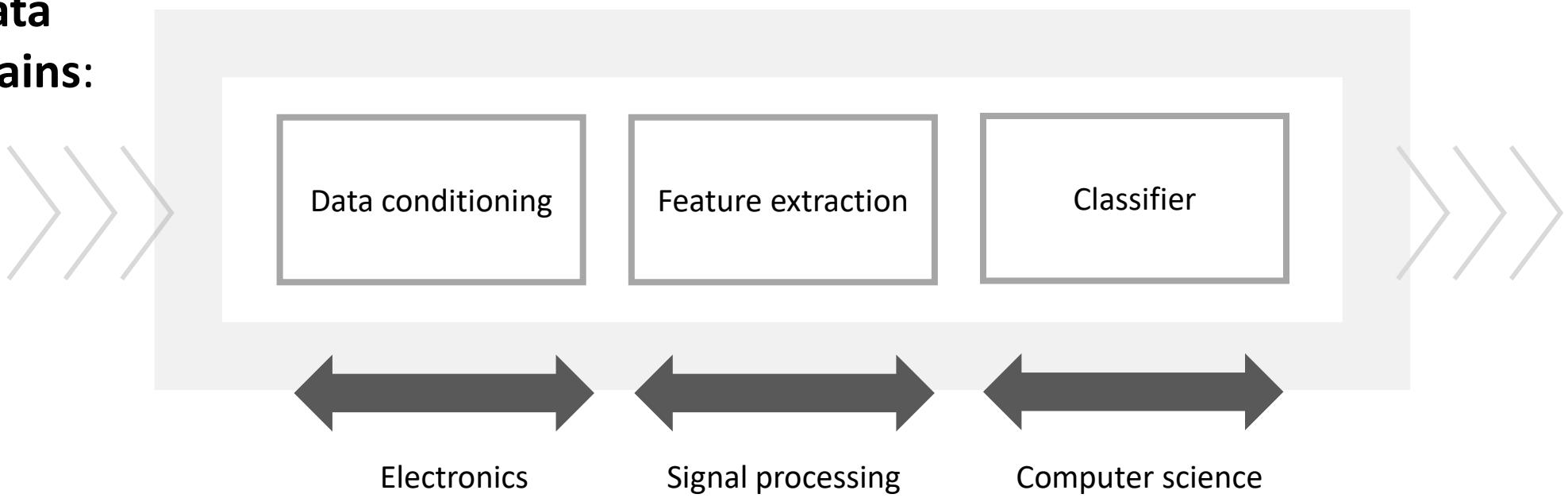


Stream-based processing - different domains of expertise

The complexity of DSP/ML processing graphs stems from the need to integrate expertise across multiple domains

Different **data physical domains**:

- Acoustics
- Electrical
- Chemical
- Mechanical
- ...

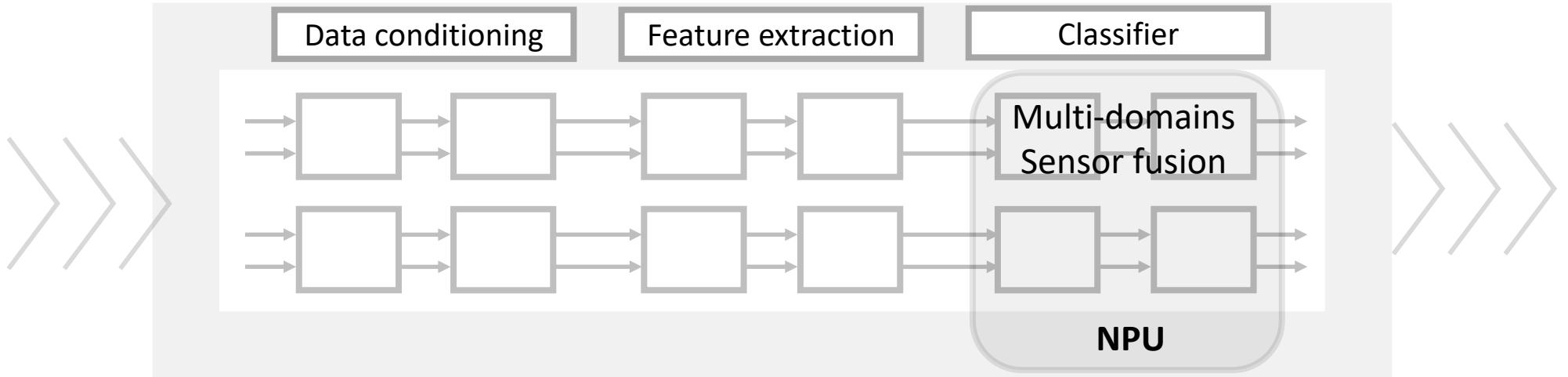


Different **software engineering domains**



Stream-based processing with graph of computing nodes

- Acoustics
- Electrical
- Chemical
- Mechanical
- ...

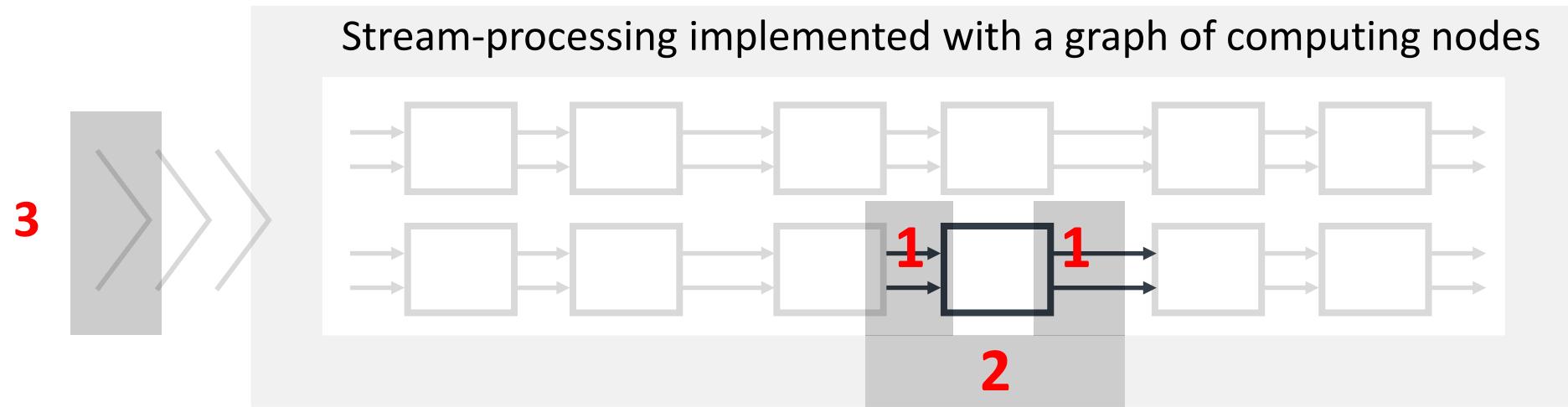


Our proposal : stream-processing is implemented with a graph of computing nodes **designed independently** (from different providers), some nodes can be pre-installed in the Flash of the platform manufacturer

The proof of concept is in production with the graph of [EEMBC audiomark](#) using four DSP nodes (beamformer, echo and noise suppressor and a [classifier node](#) for Key Word Spotting) running with or without NPU, but with the same node's interface

Manifests of interfaces for nodes, Graph-I/O, Processor

Interfaces between nodes, the scheduler, and graph I/Os are standardized and formalized

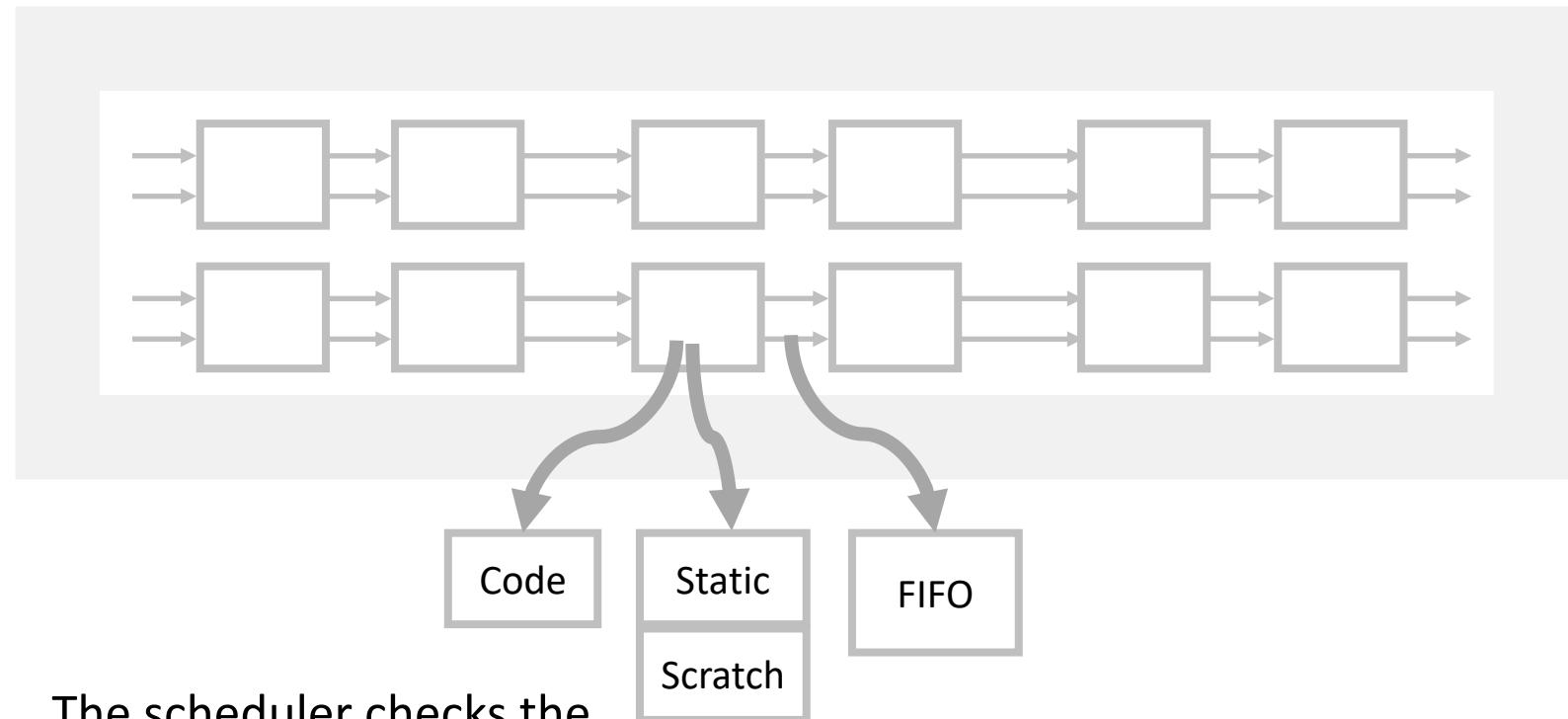


- 1 Inter-node interface** : data format (sampling rate, interleaving, raw format, frame size)
- 2 Processor interface** with nodes : memory allocation and TCM, compute libraries and NPU
- 3 Graph-I/O interfaces** : buffering and polling scheme, mixed-signal configuration of the domains

NanoGraph interpreter and scheduler

The graph intermediate format is a text file, “compiled” to build a scheduling table and a memory mapping

The compiled graph is
a linked list
referencing memory
buffers and node
addresses



The scheduler checks the
FIFO buffers before
calling a node instance



NanoGraph vs. Traditional Firmware/Monolithic DSP/ML

Aspect	NanoGraph (Graph Interpreter)	Traditional Firmware / Monolithic DSP/ML
Modularity, Extensibility	Highly modular, with independent and reusable nodes. Add new functions with minimal code. Integrates a tiny virtual machine (byte-code interpreter)	Tightly coupled code that is difficult to reuse or update. Adding features typically requires significant rewrite
Portability	Portable thanks to flexible interfaces	Hardware-specific and expensive to port
Time-to-Market, Reliability	Faster prototyping using pre-built nodes; no risk of bricking the device; self-recovery through the interpreter.	Larger source code size to manage all the possible interfaces and data formats. Manual Flow error management managed manually.
Resource Efficiency	Optimized for bare metal and tiny devices. Ease memory mapping to TCM.	Manual operations for memory mapping.
DSP/ML Integration	Transparent support for DSP/ML accelerators	Manual integration is more complex
Use-cases	Audio, Vision and environmental sensors, flexible data formats, sampling rate from months to MHz,	Audio only, fixed frame size
Other	Apache license, multiprocessing (AMP) and multi-threads, Arch32/64bits, stream flow error management	Proprietary or platform specific



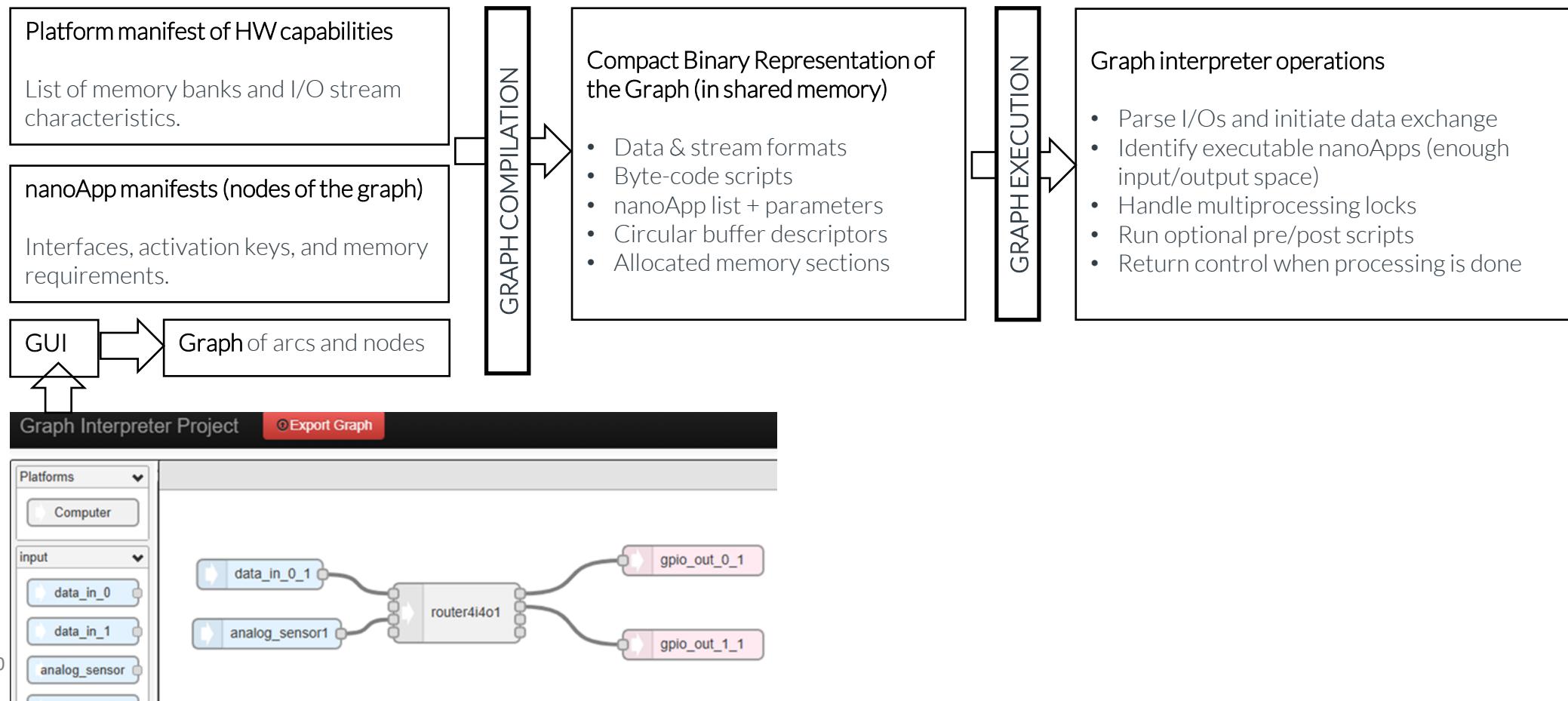
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Graph design

Compilation process using “Manifests”

The NanoGraph interpreter task is simplified with the help of “off-line” graph compilation.

Platform capabilities and I/O descriptions are defined in manifest files and used by the graph compiler.



Small memory footprint

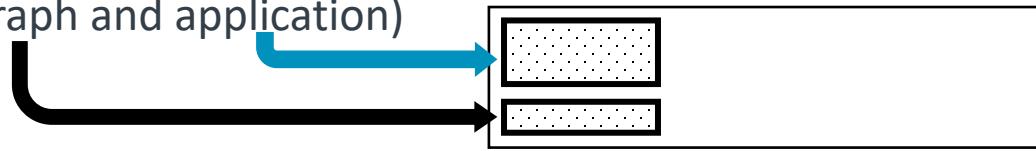
Remote sensors connected through LoRa have a data rate as low as 50Bytes/s

A graph size of two nodes (+ their respective parameters and a script) is in the 500Bytes range

An interpreter eliminates the risk of malware injection during firmware updates

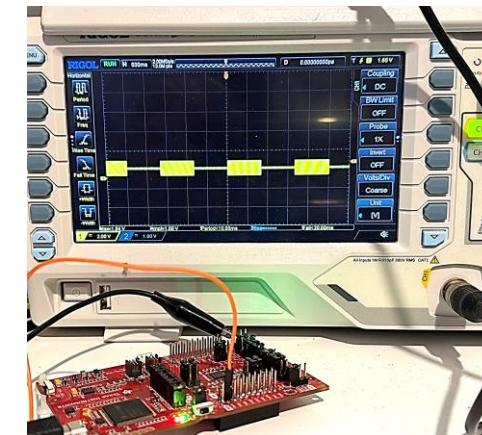
A memory map of the LoRa device :

RAM (graph and application)



Flash (graph, nodes, application)

Filter and detector nodes with 1kB-RAM



Graph with embedded scripts

A graph can incorporate nodes with interpreted code using basic integer/float arithmetics.

The instruction “SYSCALL” gives access to nodes (set/read parameters), arcs (read/write, check access time-stamps), application callbacks (change of use-case, access to I/Os and trace), compute libraries..

The script interpreter is consuming less than 100 Bytes of stack memory.

Why would you need Python for very simple operations similar to the ones of pocket calculator ?

Examples of instructions

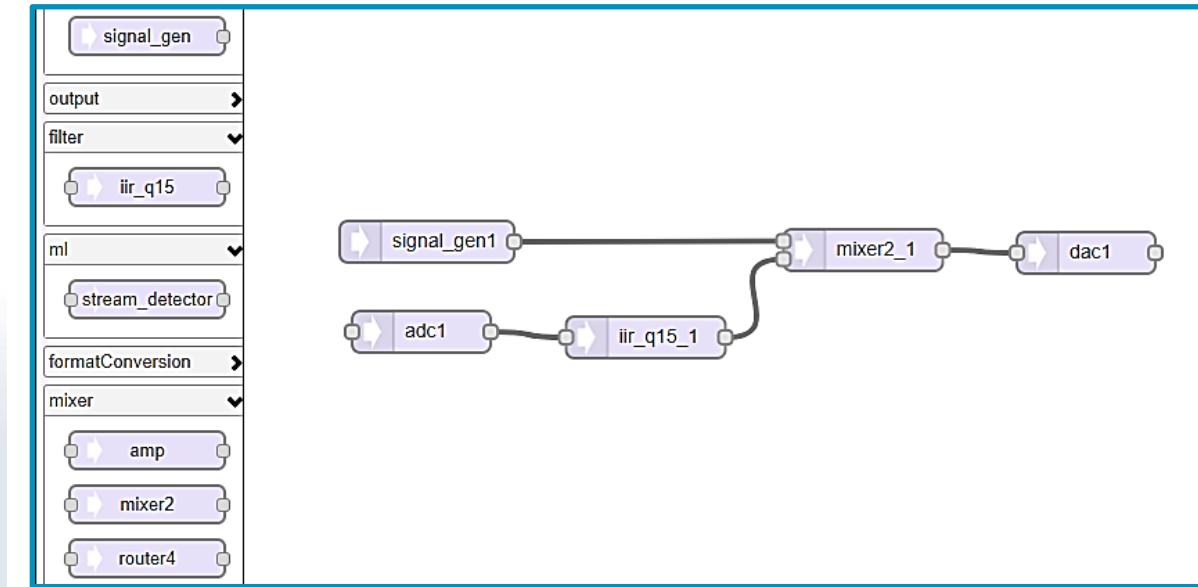
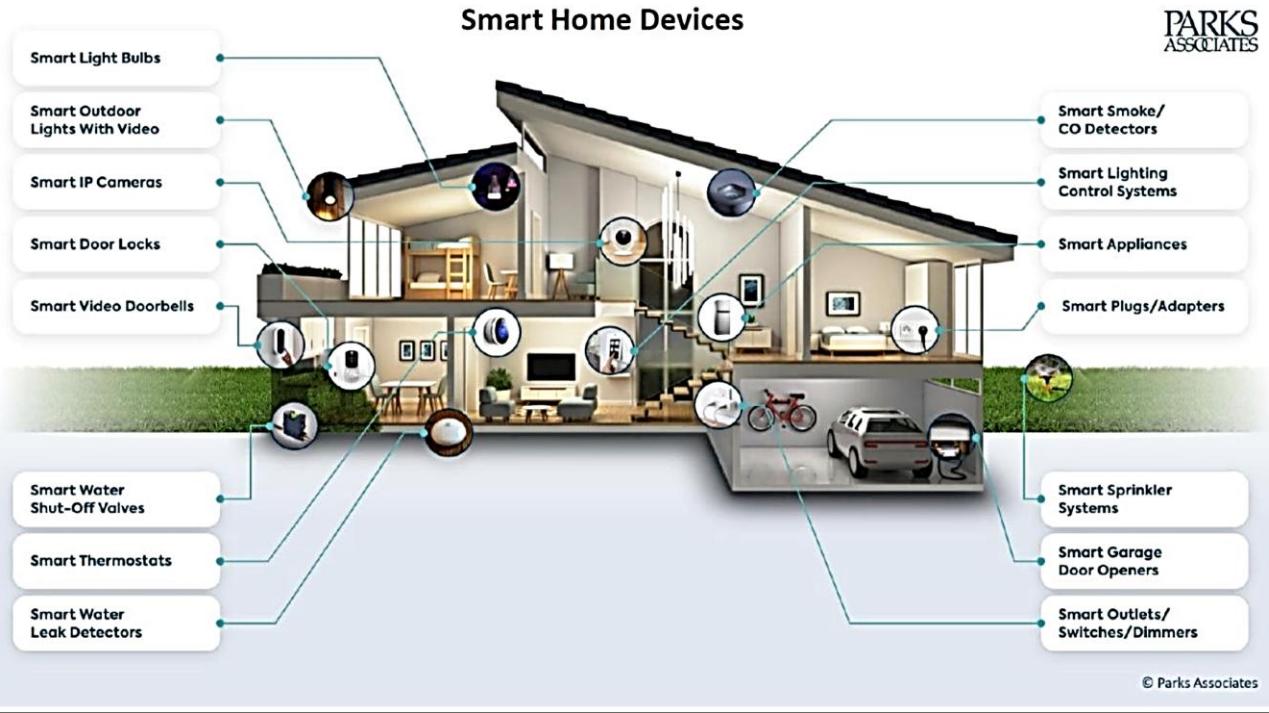
```
r6 = r5 + 3.14159  
test r6 == r5 - r4  
if_yes call label_xyz  
r3[8 15] = r2  
r3 = r4[3]  
r0[r1++] = SP  
syscall 4 r1 r5 r10
```

```
r6 = r5 + 3.14159  
test if r6 == ( r5 - r4 )  
conditional call  
bit-field load of r2 to the 2nd byte of r3  
gather load r3 = r4[3]  
scatter store with post increment r0[r1++]= top of stack  
system call #4 with the application using 3 parameters
```



Next steps : low-code for smart-home sensors

Do we need a complex programming environment to drag and drop software components from a Store ?



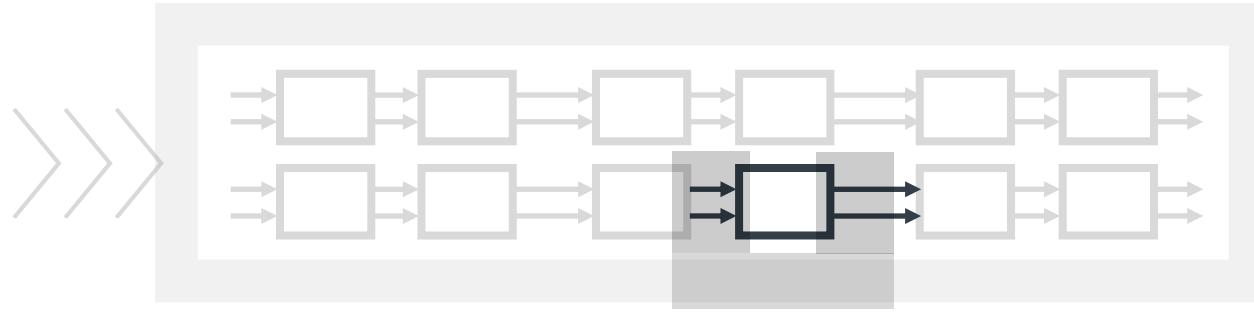
GUI proof of concept using node-RED



arm

Backup

Manifests for nodes



1 Inter-node interface and interface with the platform :

a text file (readable syntax)
done once at node delivery

```
; -----  
; SOFTWARE COMPONENT MANIFEST - "arm_stream_filter"  
;  
;  
node_developer_name    ARM          ; developer name  
node_name               arm_stream_filter ; node name  
  
node_using_arc_format  1           ; to let filter manage q15 and fp32  
node_mask_library       64          ; dependency with DSP services  
  
;  
;   MEMORY ALLOCATIONS  
  
node_mem                0           ; first memory bank (node instance)  
node_mem_alloc           76          ; amount of bytes  
  
node_mem                1           ; second memory bank (node fast working area)  
node_mem_alloc           52          ;  
node_mem_type            1           ; working memory  
node_mem_speed           2           ; critical fast  
;  
;   ARCS CONFIGURATION  
node_arc                 0           ;  
node_arc_nb_channels     {1 1 2}    ; arc interleaved, options for the number of channels  
node_arc_raw_format      {1 2 1}    ; options for the raw format STREAM_S16, STREAM_FP32  
  
node_arc                 1           ;  
node_arc_nb_channels     {1 1 2}    ; options for the number of channels  
node_arc_raw_format      {1 2 1}    ; options for the raw format STREAM_S16, STREAM_FP32  
end
```



Graph (a text file : manual input or generated by a GUI)

Nodes

```
arm_stream_filter 0
parameters
  1 u8; 0
  2 u8; 2 0
  5 h16; 1231 1D28 1231 63E8 D475
  5 h16; 1231 0B34 1231 2470 9821
end
```

node name instance index Boot preset,
Options : Memory allocation, pre/post processing script,
Dedicated architecture, processor (or any), priority, trace verbose level
Memory mapping of each segment

Arcs

```
arm_stream_filter 0 1
arm_stream_detector 0 0
```

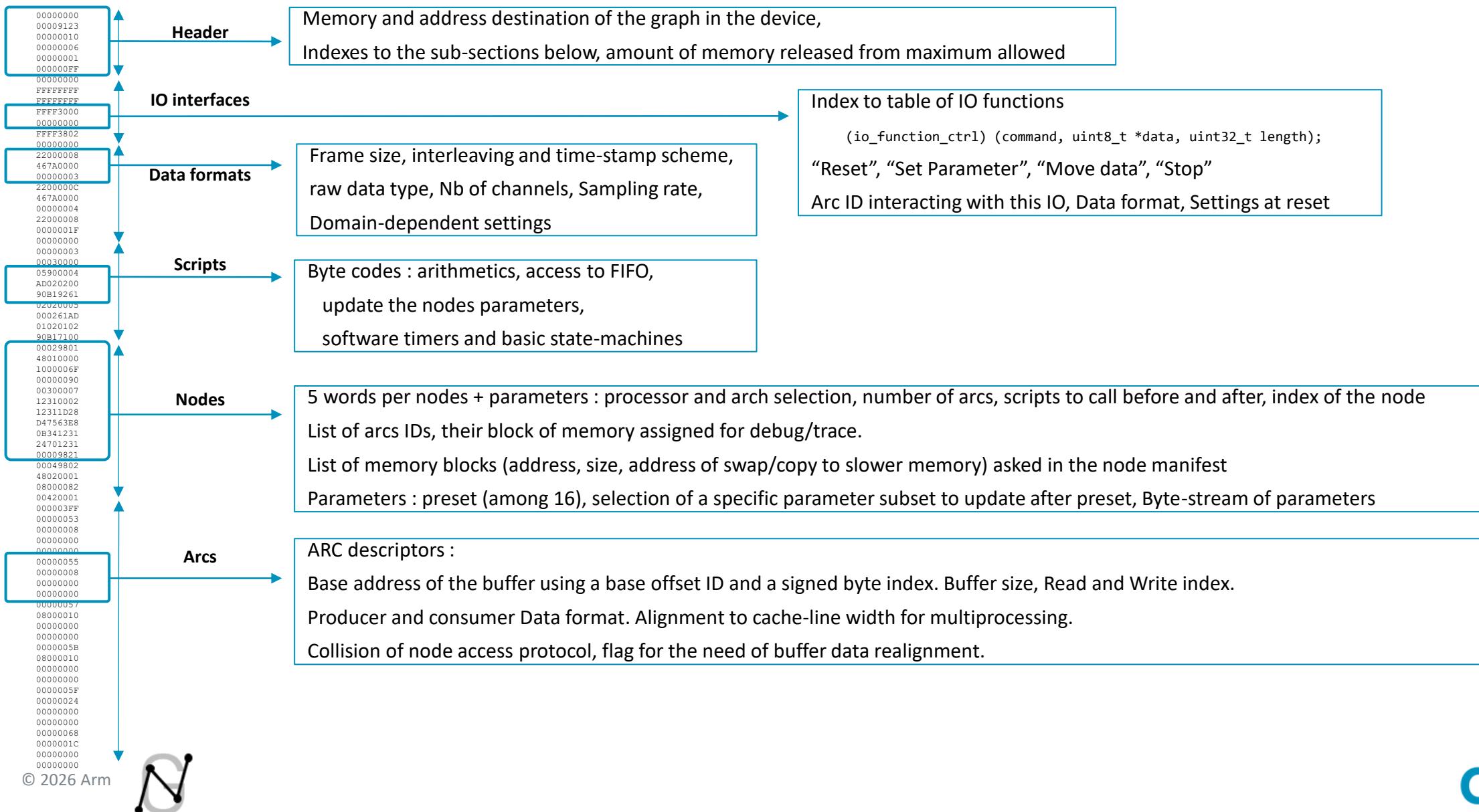
node name instance index arc output index
Node name instance index arc input index

```
arc_input 0 0
arm_stream_filter 0 0 0
```

Arcs at the boundary of the graph
node it is connected to



“Compiled” Graph (used by the scheduler)



Processor manifest : memory mapping

```
;=====
; TOP MANIFEST :
;   - paths to the files
;   - shared memories
;   - list of processors and their private memories and IOs
;   - list of the nodes installed in each processor and/or
;     architectures
;=====
6           six file paths
```

```
0 ../../stream_platform/
1 ../../stream_platform/computer/manifest/
2 ../../stream_nodes/arm/
3 ../../stream_nodes/signal-processingFR/
4 ../../stream_nodes/bitbank/
5 ../../stream_nodes/elm-lang/
```

```
;=====
3           number of processors
2           number of shared memory

;   processor and architecture ID are in the range [1..7]
;   Access      0 data/prog R/W, 1 data R, 2 R/W, 3 Prog, 4 R/W
;   Speed       0 slow/best effort, 1 fast/internal, 2 TCM
;   Type        0 Static, 1 Retention, 2 scratch mem

;---MEMID SIZE A S T   Comments
0    8000  1 0 0   shared memory
3    1000  1 0 1   simulates shared retention memory
```

```
;=====
; Processor #1 - architecture #1, two processors
; proc ID, arch ID, main proc, nb mem, service mask, I/O
1    1    1    2    15   7

;---MEMID SIZE A S T   Comments
1    1000  1 2 0   simulates DTCM
2    1000  1 2 1   simulates ITCM
```

```
;---IO AFFINITY WITH PROCESSOR 1---
; Path      Manifest    IO_AL_idx   Comments
1 io_platform_data_in_0.txt    0   application proc
1 io_platform_data_in_1.txt    1   application proc
1 io_platform_analog_sensor_0.txt 2   ADC
1 io_platform_audio_in_0.txt   4   microphone
1 io_platform_line_out_0.txt   6   audio out stereo
1 io_platform_gpio_out_0.txt   7   GPIO/LED
1 io_platform_data_out_0.txt   9   application proc
```

Shared memory declaration
**Number of memory banks below, bit-field of
 installed compute libraries**

Private memory declaration

List of streams the processor can activate

List of nodes mapped to processors

```
... (continued) ...
;=====
; Processor #2
; proc ID, arch ID, main proc, nb mem, service mask, I/O
2    1    0    2    15   2

;---MEMID SIZE A S T   Comments
1    1000  1 2 0   index 1/2 point to different physical addresses
2    1000  1 2 1   index 1/2 point to different physical addresses

;---IO AFFINITY WITH PROCESSOR 2---
; Path      IO Manifest    IO_AL_idx   Comments
1 io_platform_data_in_0.txt    0   shared with Proc 1
1 io_platform_motion_in_0.txt 3   accelero=gyro
```

```
;=====
; Processor #3 - new architecture, one processor
; proc ID, arch ID, main proc, nb mem, service mask, I/O
1    2    0    0    15   2

;---MEMID SIZE A S T   Comments
;---IO AFFINITY WITH PROCESSOR 2---
; Path      IO Manifest    IO_AL_idx   Comments
1 io_platform_2d_in_0.txt    5   camera
1 io_platform_gpio_out_1.txt 8   GPIO/PWM
```

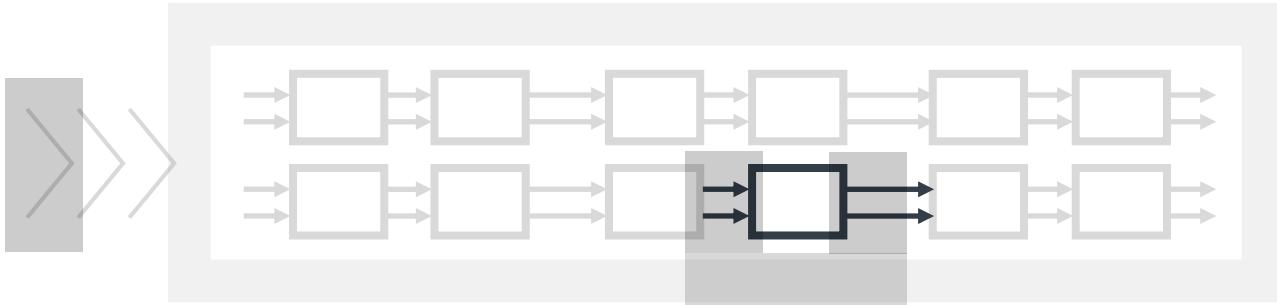
```
;===== ALL NODES =====
; scheduler algorithm :
; if the node archID > 0 then check compatibility with processor archID and exit
; if the node procID > 0 then check compatibility with processor procID and exit
;

;   Path          Node Manifest          PROC ARCH | ID
2   script/node_manifest_script.txt    0 0 | 1 runs everywhere
2   router/node_manifest_router.txt  0 1 | 2 SMP on archID-1
2   amplifier/node_manifest_amplifier.txt 0 1 | 3
2   filter/node_manifest_filter.txt  0 1 | 4
2   modulator/node_manifest_modulator.txt 0 1 | 5
2   demodulator/node_manifest_demodulator.txt 0 1 | 6
3   detector/node_manifest_detector.txt 0 1 | 7
3   resampler/node_manifest_resampler.txt 0 1 | 8
3   compressor/node_manifest_compressor.txt 0 1 | 9
3   decompressor/node_manifest_decompressor.txt 0 1 | 10
4   JPEGENC/node_manifest_bitbank_JPEGENC.txt 0 1 | 11
5   TJpgDec/node_manifest_TjpgDec.txt 0 1 | 12
;
2   filter2D/node_manifest_filter2D.txt 2 2 | 13 only archID-2
3   detector2D/node_manifest_detector2D.txt 0 2 | 14 single processor
;
end ; the platform manifest ends here
=====
```



Manifests of interfaces for Graph-I/Os

3



3 Graph-I/O interfaces :

a text file (readable syntax)

done once at platform manufacturing

```
io_platform_sensor_in_0          ; name for the tools
analog_in                         ; domain name, unit: dB, Vrms, mV/Gauss, dps, kWh, ...
                                    ; options for the raw arithmetics computation format here STREAM_S16
io_commander0_servant1 1          ; commander=0 servant=1 (default is servant)
io_buffer_allocation   2.0 1        ; default is 0, which means the buffer is declared outside of the graph, VID 1
io_direction_rx0tx1    1          ; direction of the stream 0:input 1:output from graph point of view
io_raw_format          {1 17}      ; multichannel interleaved (0), deinterleaved by frame-size (1) + options for the number of channels
io_nb_channels         {1 1 2}
io_frame_length        {1 2 16}
io_subtype_units       104
io_anologscale        0.55
io_sampling_rate       {1 16000 44100 48000} ; sampling rate options (enumeration in Hz)
io_rescale_factor      12.24 -44.3 ; [1/a off] analog_input = invinterpa x ((samples/Full_Scale_Digital) - interpooff)
end
```



Graph API (one entry-point to the scheduler)

1) Graph interpreter interface for the application :

```
void arm_graph_interpreter (uint32_t command, arm_stream_instance_t *S, uint8_t *data, uint32_t size)
```

Commands : reset the graph, execute, check boundary FIFO filling state and move data in/out, update the use-case

Instance : structure of pointers to the graph, to the installed nodes and application callbacks, to the data stream interfaces functions (below), control fields and static memory of the scheduler instance.

2) Stream interfaces used by the scheduler to initiate data moves (abstraction layer of the BSP):

```
void (io_function_ctrl) (uint32_t command, uint8_t *data, uint32_t length);
```

Commands : set buffer, set parameters, data move, stop

3) One callback, after data moves (to update the FIFO descriptors) :

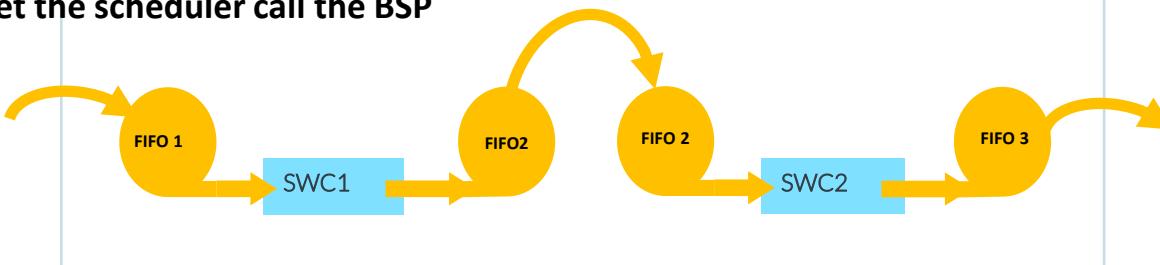
```
void arm_graph_interpreter_io_ack (uint8_t fw_io_idx, uint8_t *data, uint32_t data_size)
```

4) One prototype for all nodes :

```
void node_XXXX (uint32_t command, void *instance, void *data, uint32_t *status)
```

command = reset, set parameters, run, stop

“manual” flow control from the application or
let the scheduler call the BSP



Abstraction layer of IOs : data-move and settings + callback to set the FIFO
or
Data move from the application with same functions for FIFO setting



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Thank You

Danke

Gracias

Grazie

謝謝

ありがとう

Asante

Merci

감사합니다

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