Machine Learning inference with the BondMachine project

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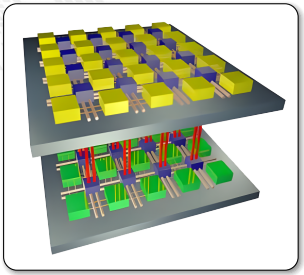
Outline

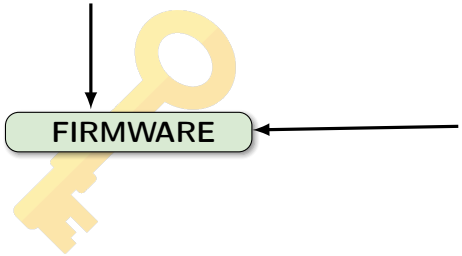
Introduction

FPGA

A field programmable gate array (FPGA) is an integrated circuit whose logic is re-programmable.

- Parallel computing
- Highly specialized
- Energy efficient

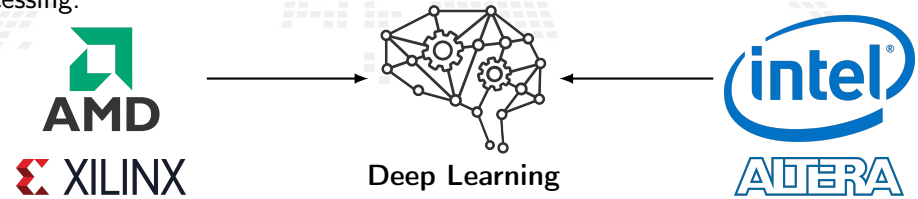




- Array of programmable logic blocks
- Logic blocks configurable to perform complex functions
- The configuration is specified with the hardware description language

Integration of neural networks on FPGA

FPGAs are playing an increasingly important role in the industry sampling and data processing.



In the industrial field

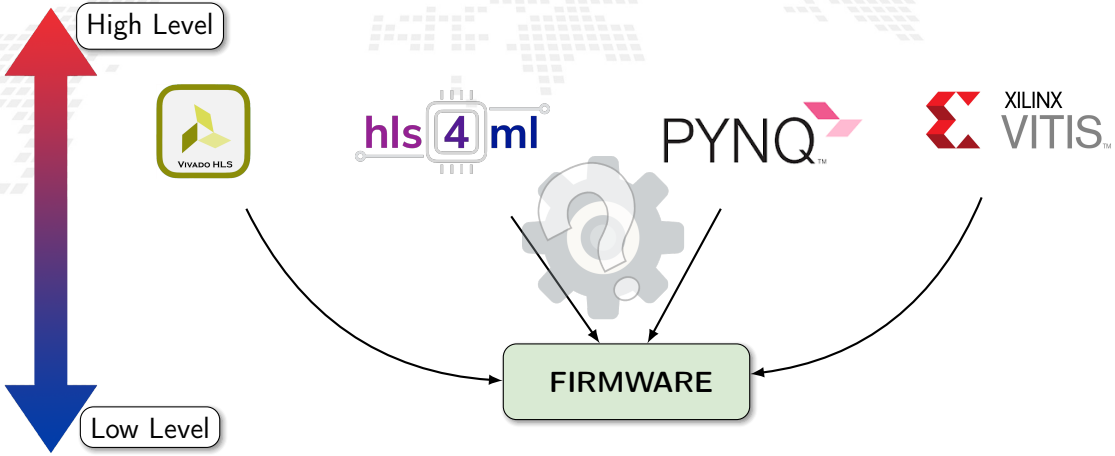
- Intelligent vision;
- Financial services;
- Scientific simulations;
- Life science and medical data analysis;

In the scientific field

- Real time deep learning in particle physics;
- Hardware trigger of LHC experiments;
- And many others ...

Firmware generation

Many projects have the goal of abstracting the firmware generation and use process.



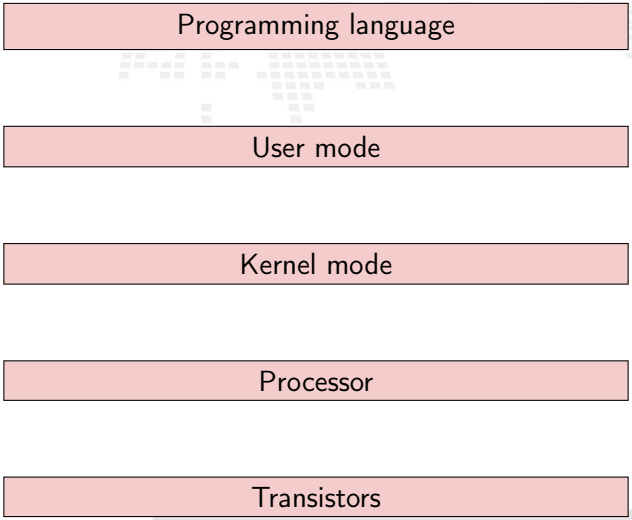
Layer, Abstractions and Interfaces

A Computing system is a matter of abstraction and interfaces. A lower layer exposes its functionalities (via interfaces) to the above layer hiding (abstraction) its inner details.

The quality of a computing system is determined by how abstractions are simple and how interfaces are clean.

Layers, Abstractions and Interfaces

An example



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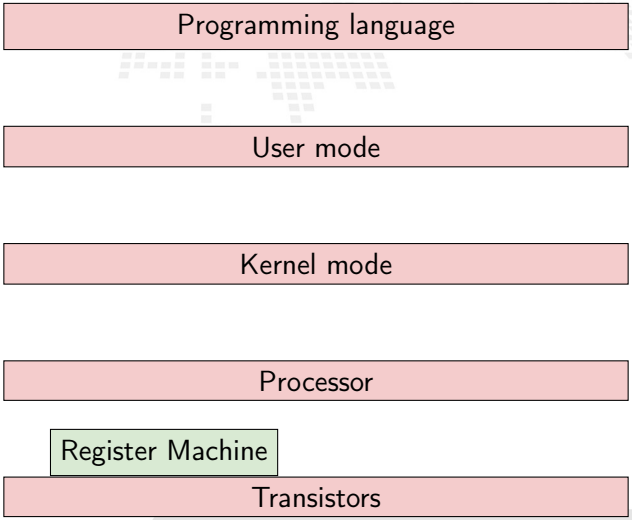

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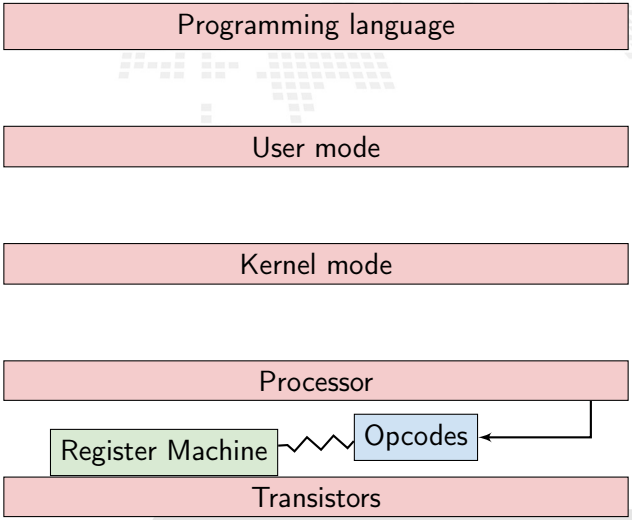

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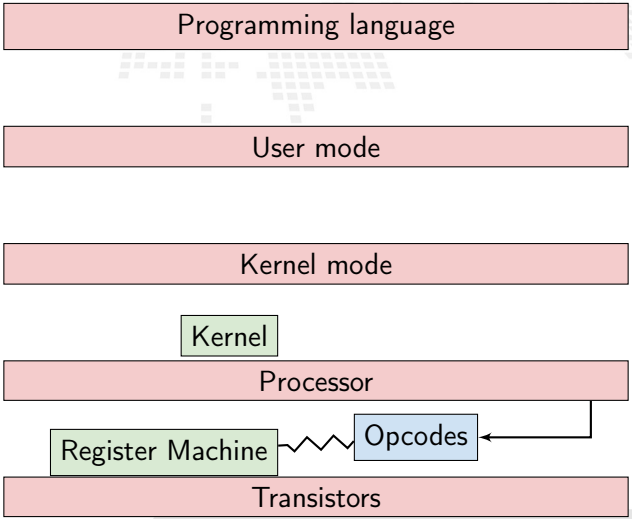

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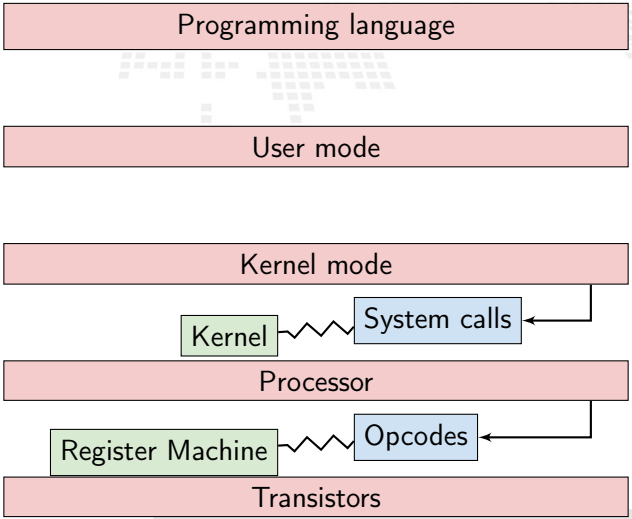

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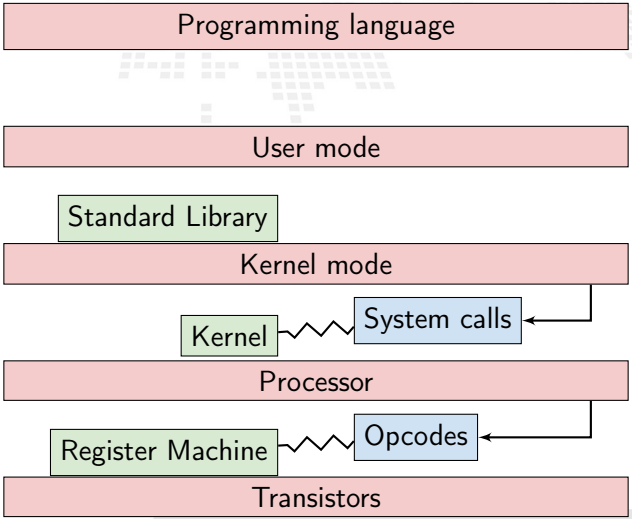

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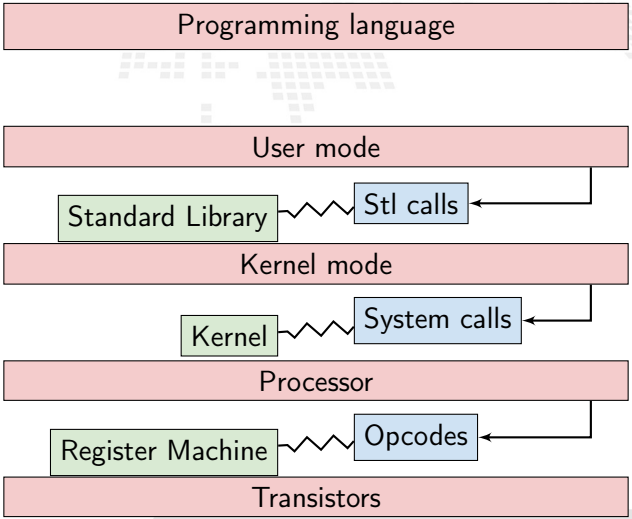

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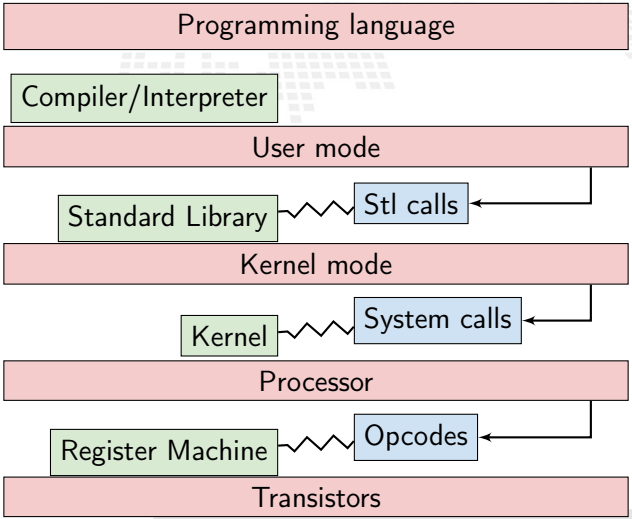

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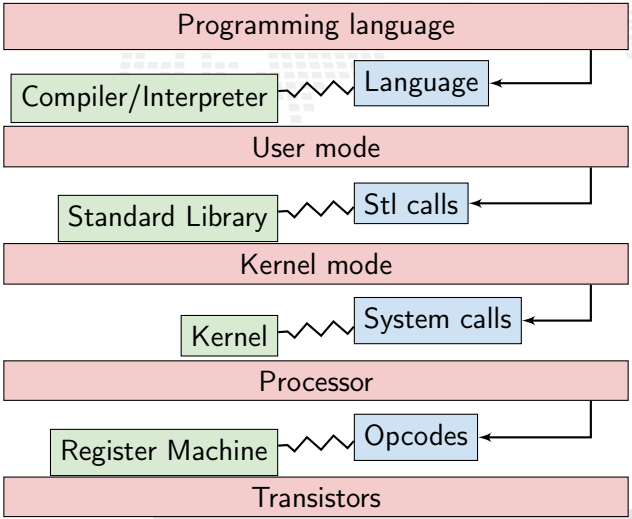

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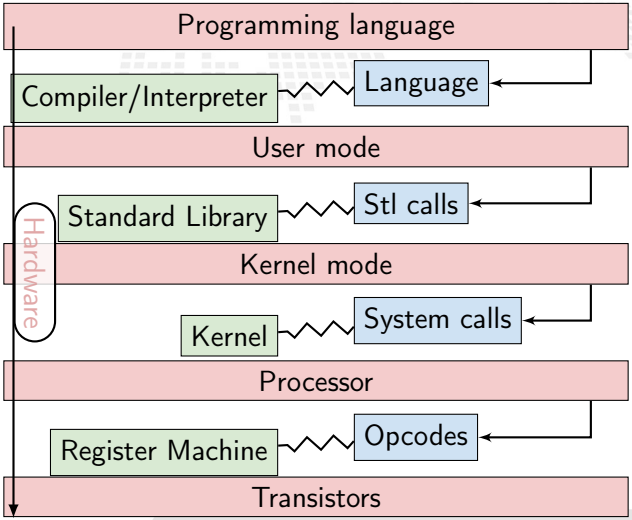

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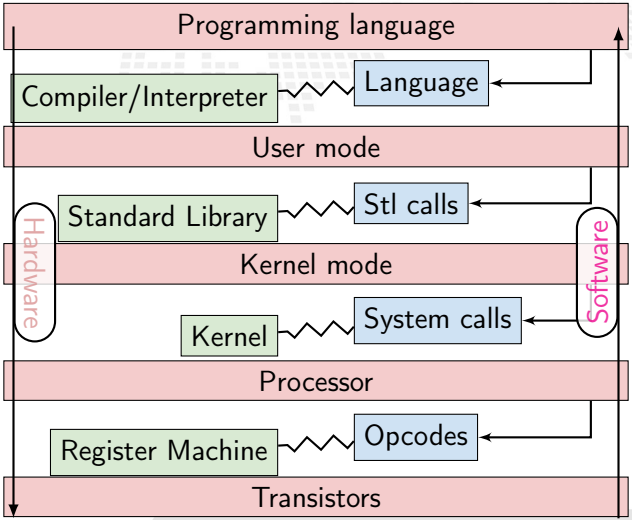

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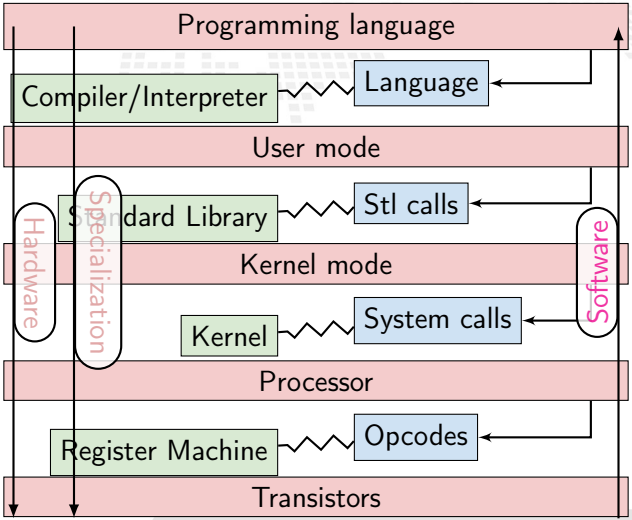

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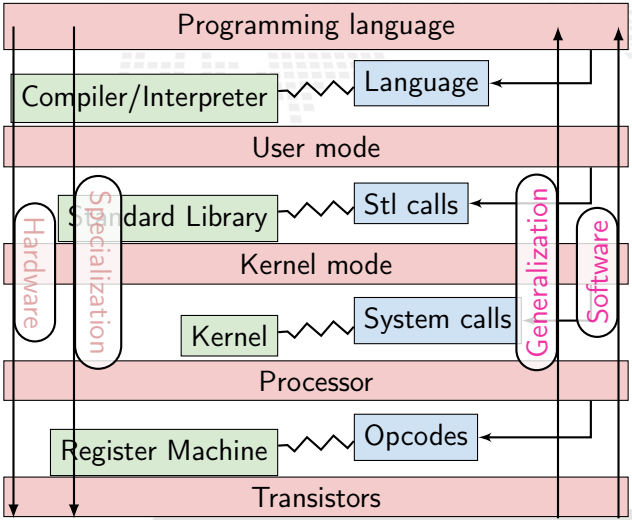

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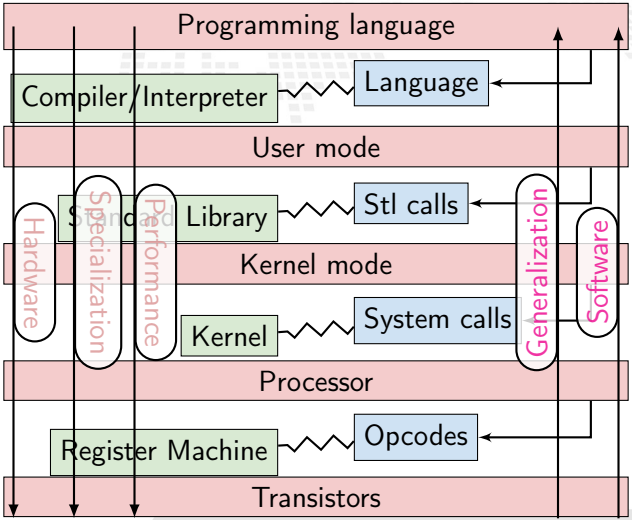

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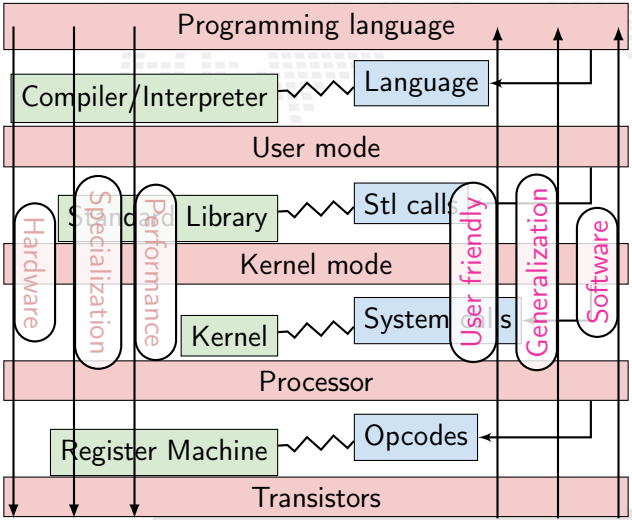
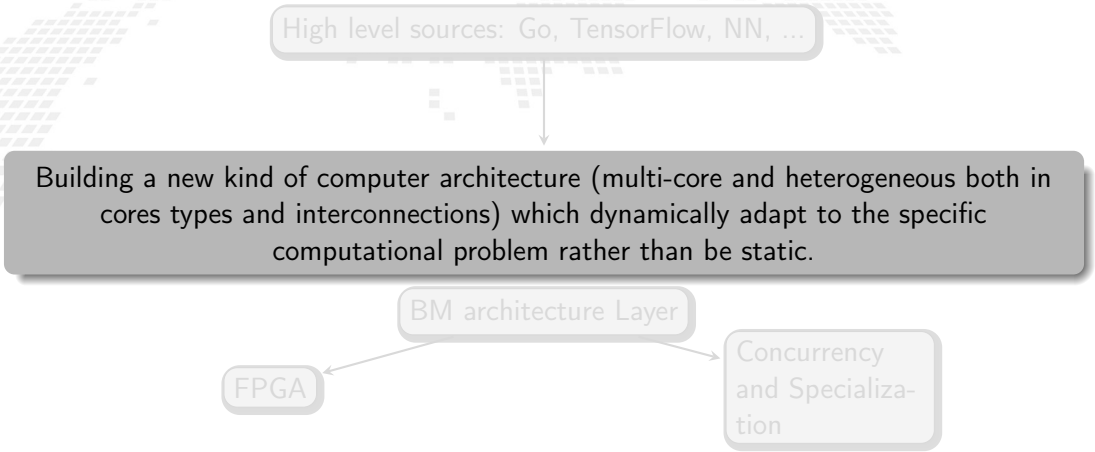


The BondMachine project

The BondMachine



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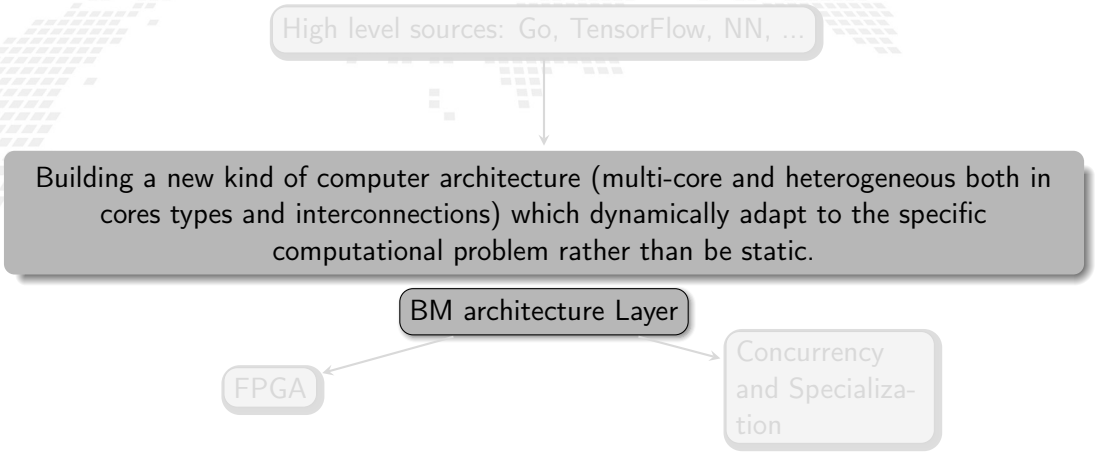
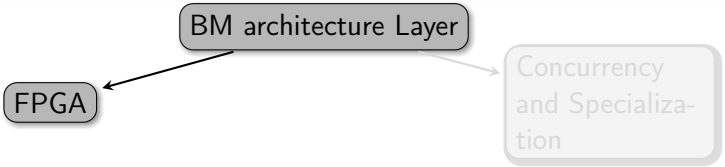


The BondMachine

High level sources: Go, TensorFlow, NN, ...

Building a new kind of computer architecture (multi-core and heterogeneous both in cores types and interconnections) which dynamically adapt to the specific computational problem rather than be static.



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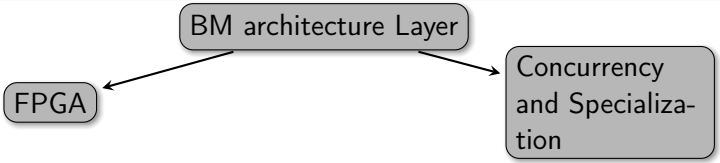

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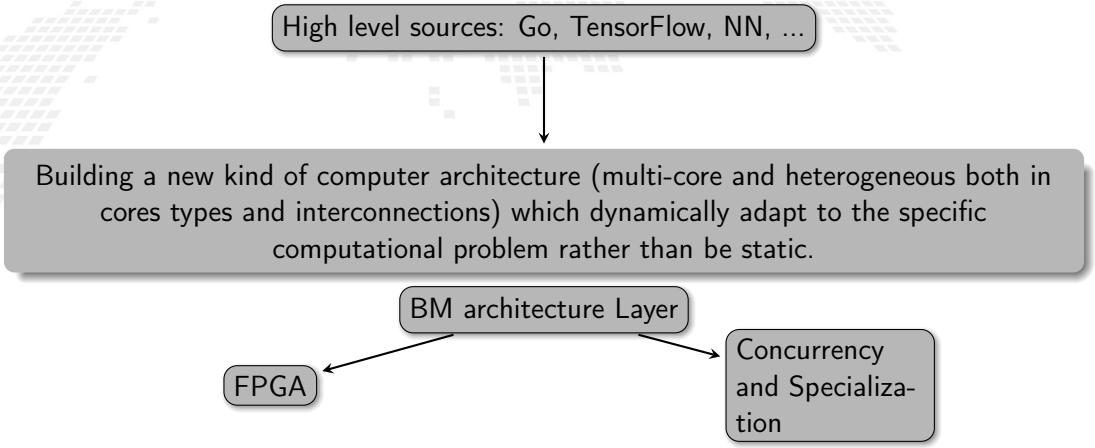

Introducing the BondMachine (BM)

The BondMachine is a software ecosystem for the dynamic generation of computer architectures that:

- Are composed by many, possibly hundreds, computing cores.
- Have very small cores and not necessarily of the same type (different ISA and ABI).
- Have a not fixed way of interconnecting cores.
- May have some elements shared among cores (for example channels and shared memories).

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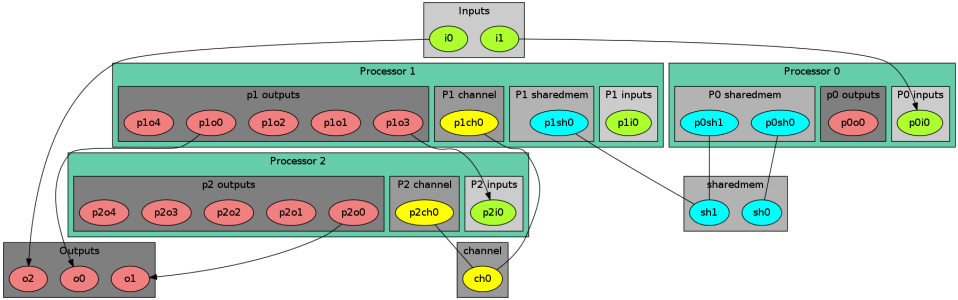

Connecting Processor (CP)

The computational unit of the BM

The atomic computational unit of a BM is the "connecting processor" (CP) and has:

- Some general purpose registers of size **Rsize**.
- Some I/O dedicated registers of size **Rsize**.
- A set of implemented opcodes chosen among many available.
- Dedicated ROM and RAM.
- Three possible operating modes.

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General purpose registers

2^R registers: r0,r1,r2,r3 ... $r2^R$

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I/O specialized registers

N input registers: i0,i1 ... iN
M output registers: o0,o1 ... oM

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Full set of possible opcodes

adc,add,addf,addi,and,chc,chw,cil,cilc,cir,cirn,clc,clr,cpy,cset,dec,div,divf,dpc,expf,hit
hlt,i2r,i2rw,incc,inc,j,jc,je,jgt0f,jlt,jlte,jr,jz,lfsr82,lfsr162r,m2r,mod,mulc,mult,multf
nand,nop,nor,not,or,r2m,r2o,r2owa,r2owaa,r2s,r2v,r2vri,ro2r,ro2rri,rsc,rset,sic,s2r,saj,sbc
sub,wrd,wwr,xnor,xor

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RAM and ROM

- 2^L RAM memory cells.
- 2^O ROM memory cells.

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Operating modes

- Full Harvard mode.
- Full Von Neuman mode.
- Hybrid mode.

Shared Objects (SO)

The non-computational element of the BM

Alongside CPs, BondMachines include non-computing units called "Shared Objects" (SO).

Examples of their purposes are:

- Data storage (Memories).
- Message passing.
- CP synchronization.

A single SO can be shared among different CPs. To use it CPs have special instructions (opcodes) oriented to the specific SO.

Four kind of SO have been developed so far: the Channel, the Shared Memory, the Barrier and a Pseudo Random Numbers Generator.

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Handle BM computer architectures

The BM computer architecture is managed by a set of tools to:

- build a specify architecture
- modify a pre-existing architecture
- simulate or emulate the behavior
- generate the Hardware Description Language Code (HDL)

Processor Builder

Selects the single processor, assembles and disassembles, saves on disk as JSON, creates the HDL code of a CP

BondMachine Builder

Connects CPs and SOs together in custom topologies, loads and saves on disk as JSON, create BM's HDL code

Simulation Framework

Simulates the behaviour, emulates a BM on a standard Linux workstation

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Processor Builder

Procbuilder is the CP manipulation tool.

- CP Creation
- CP Load/Save
- CP Assembler/Disassembler
- CP HDL

Examples

(32 bit registers counter machine)

```
procbuilder -register-size 32 -opcodes clr,cpy,dec,inc,je,jz
```

(Input and Output registers)

```
procbuilder -inputs 3 -outputs 2 ...
```

Processor Builder

Procbuilder is the CP manipulation tool.

- CP Creation
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Examples

(Loading a CP)

```
procbuilder -load-machine conproc.json ...
```

(Saving a CP)

```
procbuilder -save-machine conproc.json ...
```

Processor Builder

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Examples

(Assembling)

procbuilder -input-assembly program.asm ...

(Disassembling)

procbuilder -show-program-disassembled ...

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Examples

(Create the CP RTL code in Verilog)

```
procbuilder -create-verilog ...
```

(Create testbench)

```
procbuilder -create-verilog-testbench test.v ...
```

BondMachine Builder

Bondmachine is the tool that compose CP and SO to form BondMachines.

- BM CP insert and remove
- BM SO insert and remove
- BM Inputs and Outputs
- BM Bonding Processors and/or IO
- BM Visualizing or HDL

Examples

(Add a processor)

bondmachine -add-domains proc.json ... ; ... -add-processor 0

(Remove a processor)

bondmachine -bondmachine-file bmach.json -del-processor n

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Examples

(Add a Shared Object)

bondmachine -add-shared-objects specs ...

(Connect an SO to a processor)

bondmachine -connect-processor-shared-object ...

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Examples

(Adding inputs or outputs)

bondmachine -add-inputs ... ; bondmachine -add-outputs ...

(Removing inputs or outputs)

bondmachine -del-input ... ; bondmachine -del-output ...

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Examples

(Bonding processor)

bondmachine -add-bond p0i2,p1o4 ...

(Bonding IO)

bondmachine -add-bond i2,p0i6 ...

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Examples

(Visualizing)

bondmachine -emit-dot ...

(Create RTL code)

bondmachine -create-verilog ...

Toolchains

A set of toolchains allow the build and the direct deploy to a target device of BondMachines

Bondgo Toolchain main targets

A file local.mk contains references to the source code as well all the build necessities
make bondmachine creates the JSON representation of the BM and assemble its code
make hdl creates the HDL files of the BM
make show displays a graphical representation of the BM
make simulate [simbatch] start a simulation [batch simulation]
make bitstream [design_bitstream] create the firwware [accelerator firmware]
make program flash the device into the destination target

Simulation

An important feature of the tools is the possibility of simulating BondMachine behavior.

An event input file describes how BondMachines elements has to change during the simulation timespan and which one has to be be reported.

The simulator can produce results in the form of:

- Activity log of the BM internal.
- Graphical representation of the simulation.
- Report file with quantitative data. Useful to construct metrics

Graphical simulation in action

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An event input file describes how BondMachines elements has to change during the simulation timespan and which one has to be be reported.

The simulator can produce results in the form of:

- Activity log of the BM internal.
- Graphical representation of the simulation.
- Report file with quantitative data. Useful to construct metrics

Graphical simulation in action

Emulation

The simulation facility is not necessarily used for debug purposes, it can be used also to run payloads without having a real FPGA.

The same engine that simulate BondMachines can be used as emulator.

Through the emulator BondMachines can be used on Linux workstations.

Molding the BondMachine

As stated before BondMachines are not general purpose architectures, and to be effective have to be shaped according the specific problem.

Several methods (apart from writing in assembly and building a BondMachine from scratch) have been developed to do that:

- *bondgo*: A new type of compiler that create not only the CPs assembly but also the architecture itself.
- *basm*: The BondMachine Assembler.
- A set of API to create BondMachine to fit a specific computational problems.
- An Evolutionary Computation framework to "grow" BondMachines according some fitness function via simulation.
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Use the BM computer architecture

Mapping specific computational problems to BMs

Symbond

Map symbolic mathematical expressions to BM

Boolbond

Map boolean systems to BM

Matrixwork

Basic matrix computation

Basm

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Map computational graphs to BM

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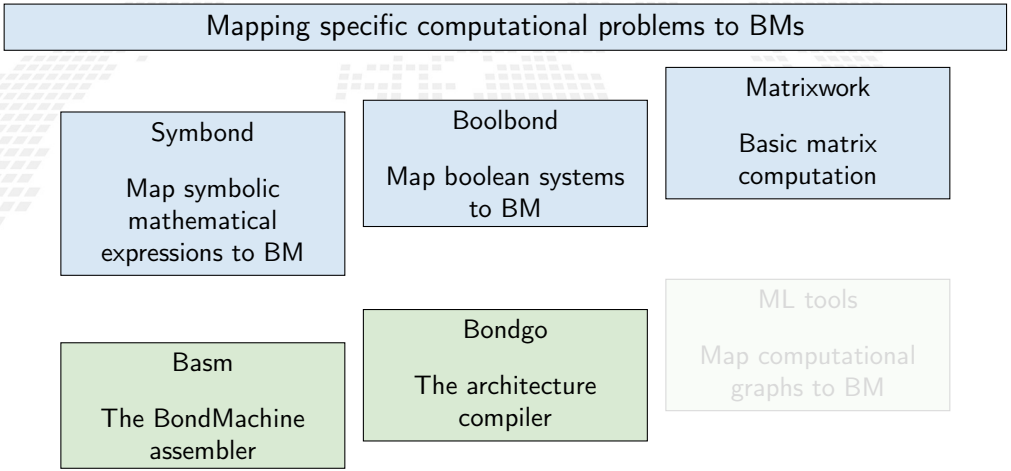

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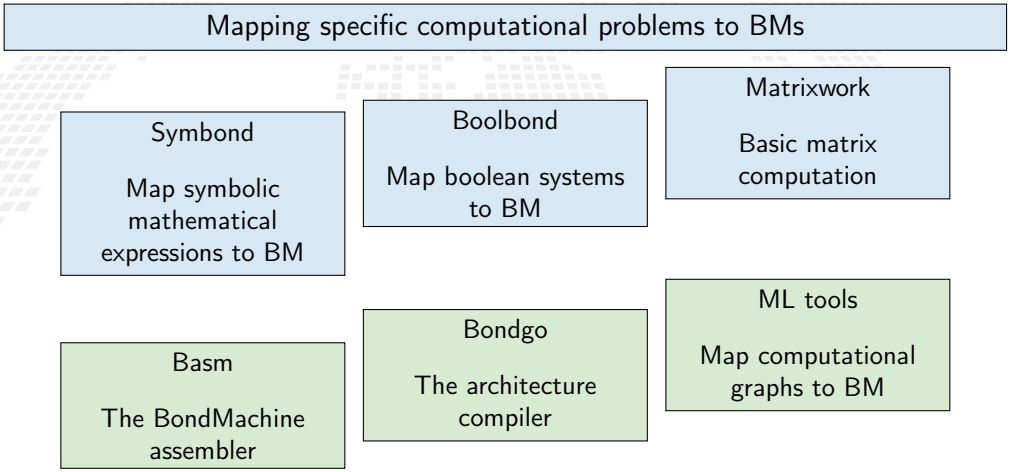

more about these tools

Bondgo

The major innovation of the BondMachine Project is its compiler.

Bondgo is the name chosen for the compiler developed for the BondMachine.

The compiler source language is Go as the name suggest.

Bondgo

This is the standard flow when building computer programs

Bondgo

This is the standard flow when building computer programs

high level language source

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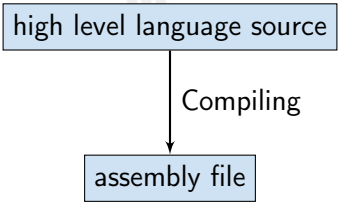

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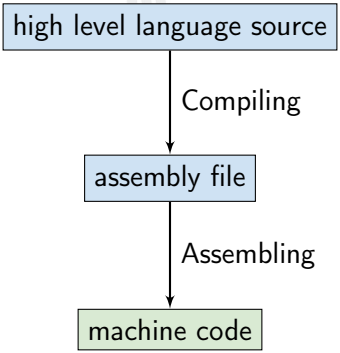

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Bondgo does something different from standard compilers ...

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high level GO source

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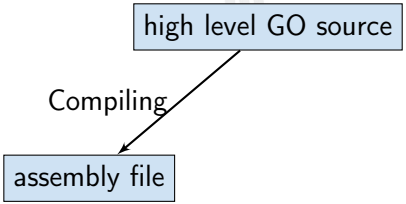

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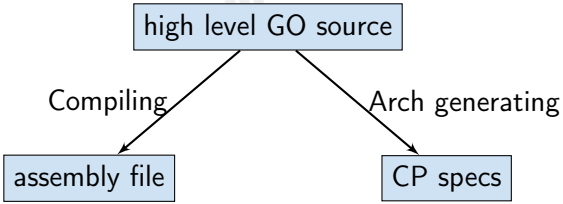

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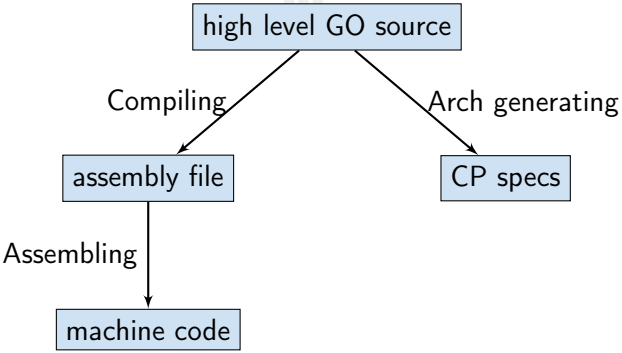

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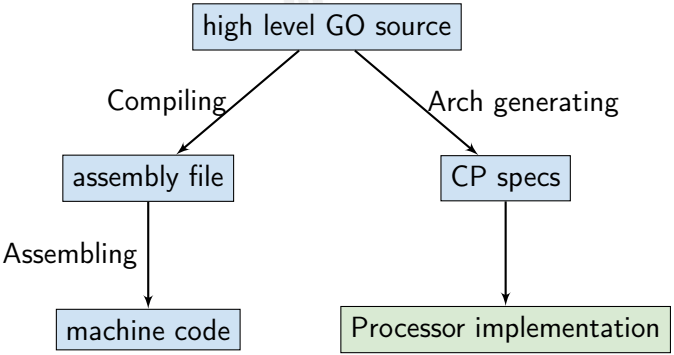

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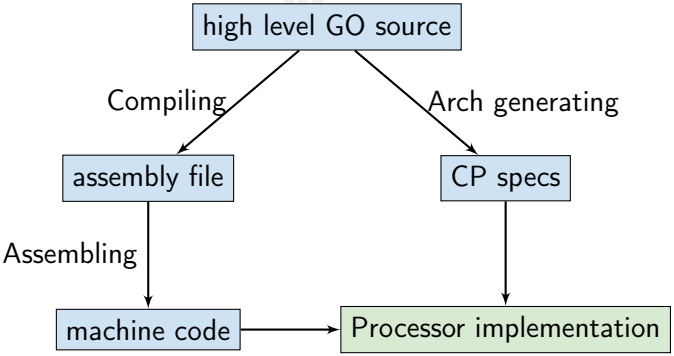
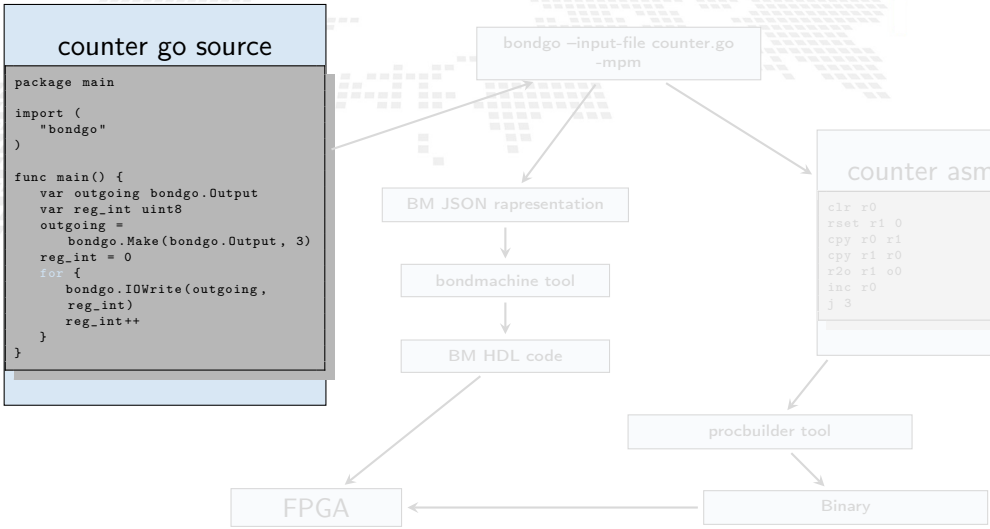


Bondgo workflow example



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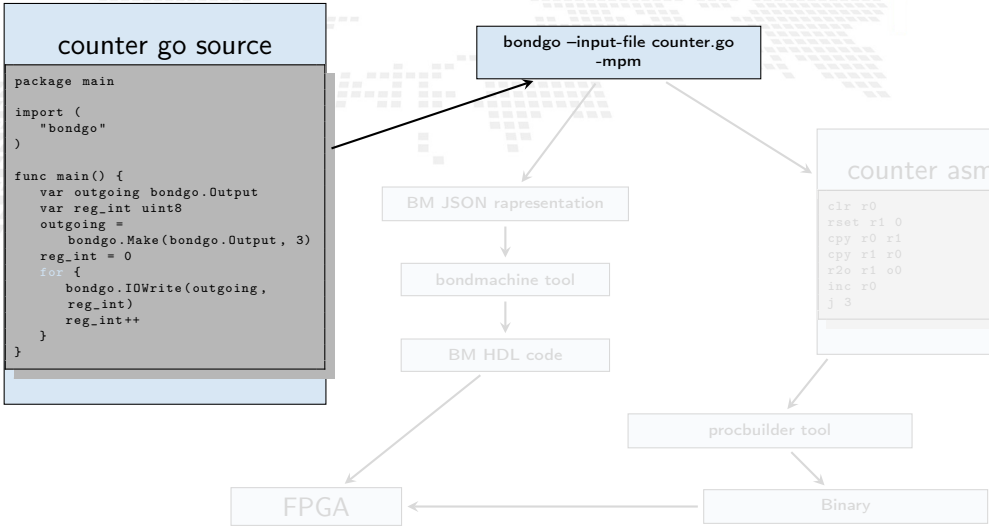

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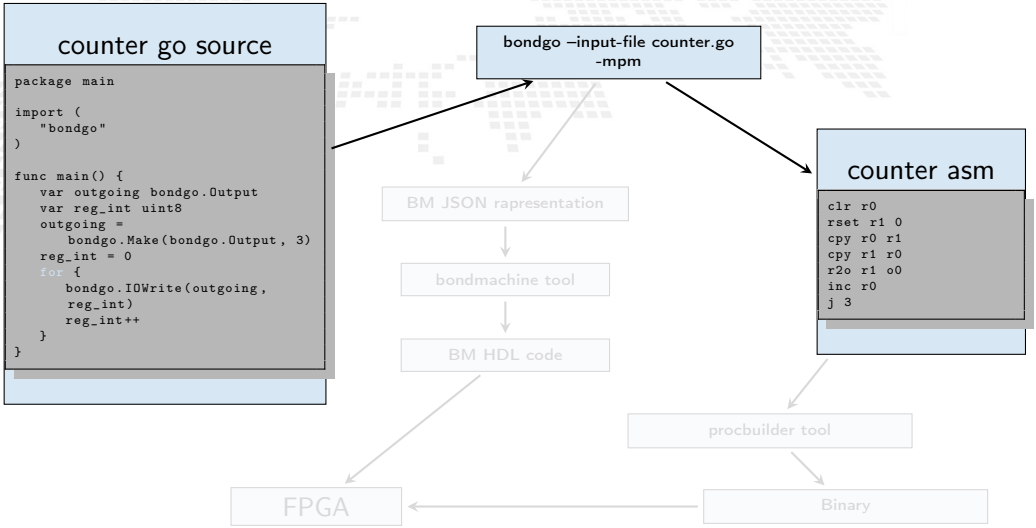

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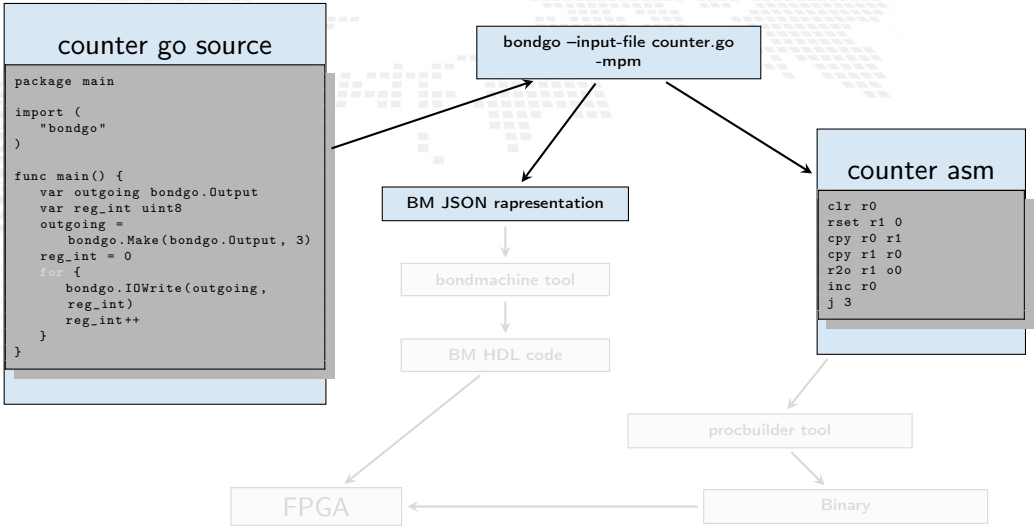

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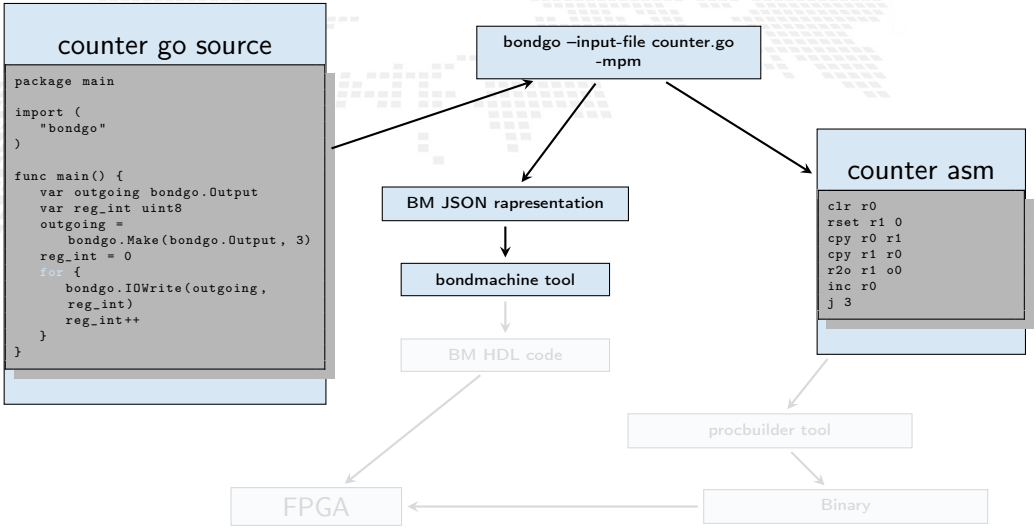

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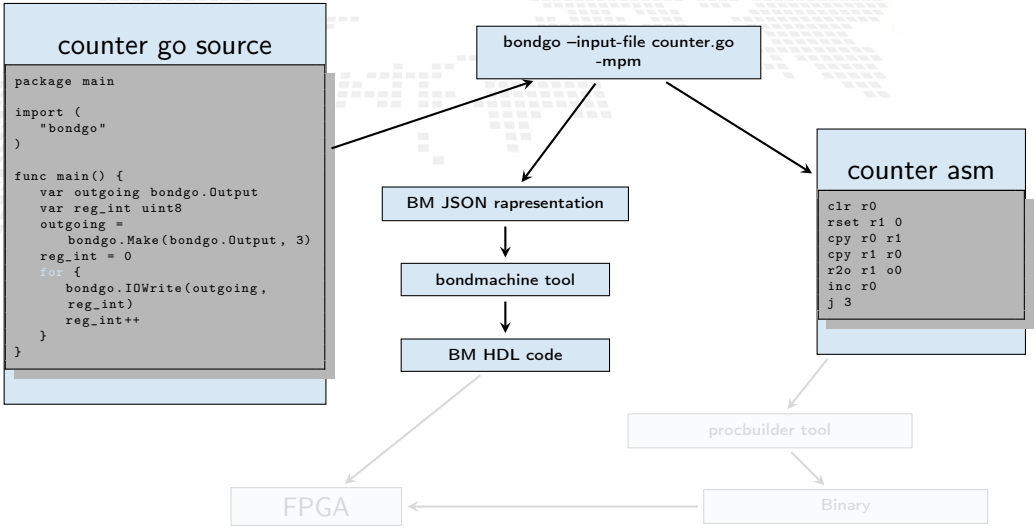

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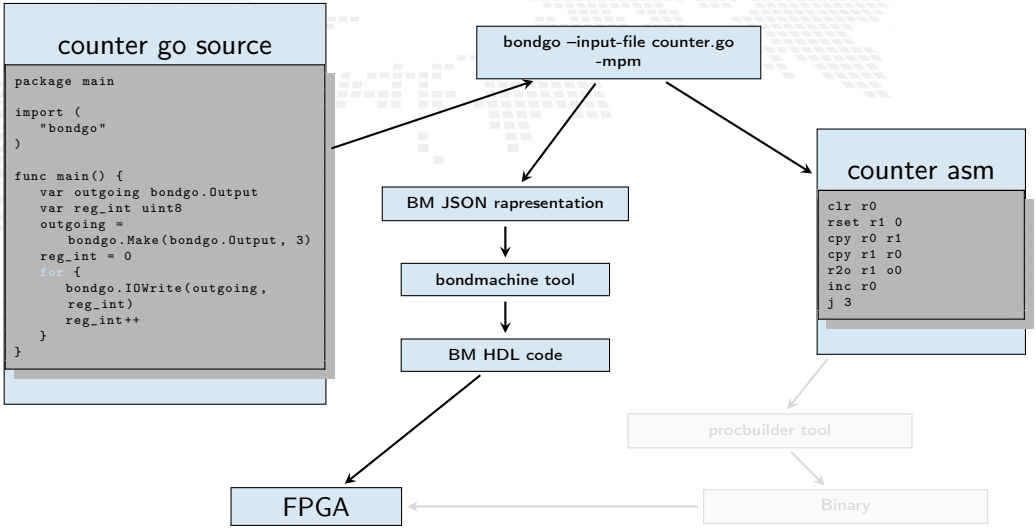

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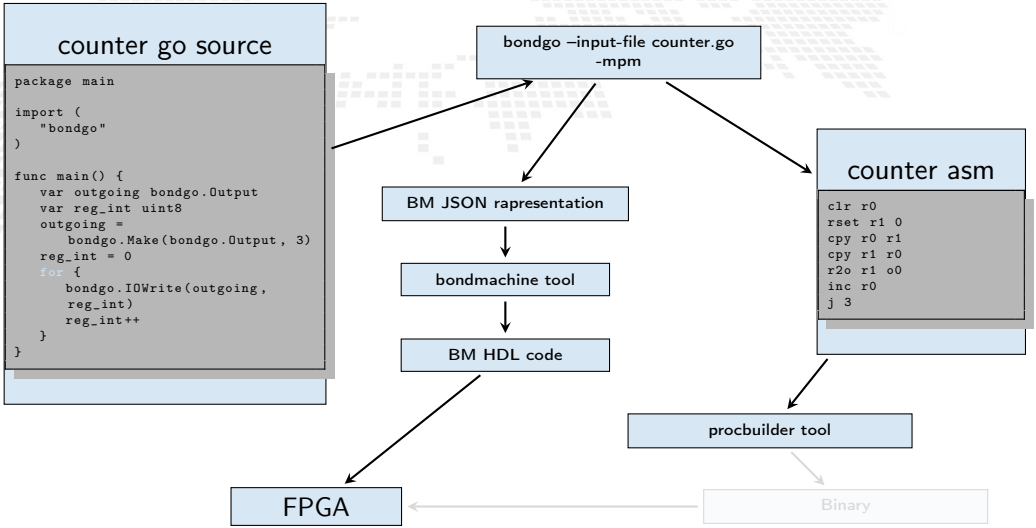

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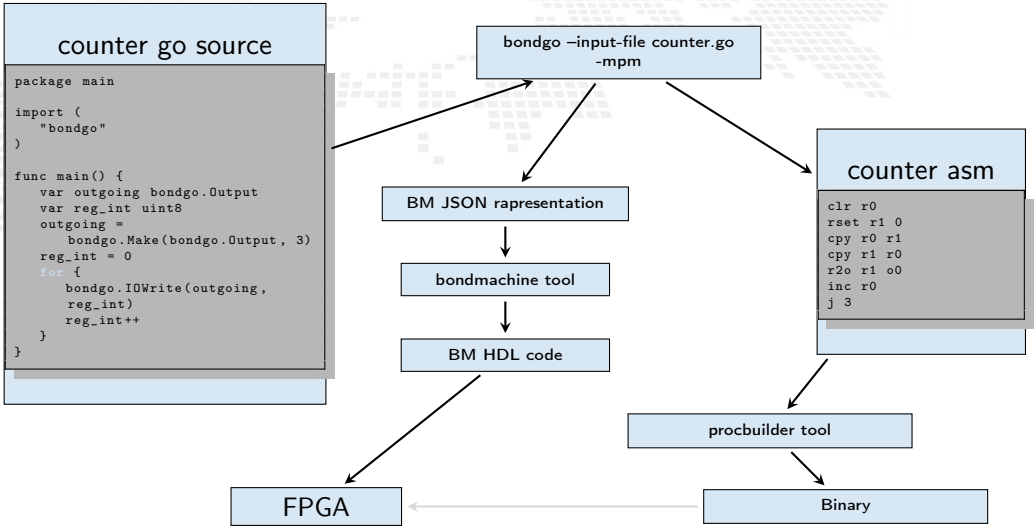

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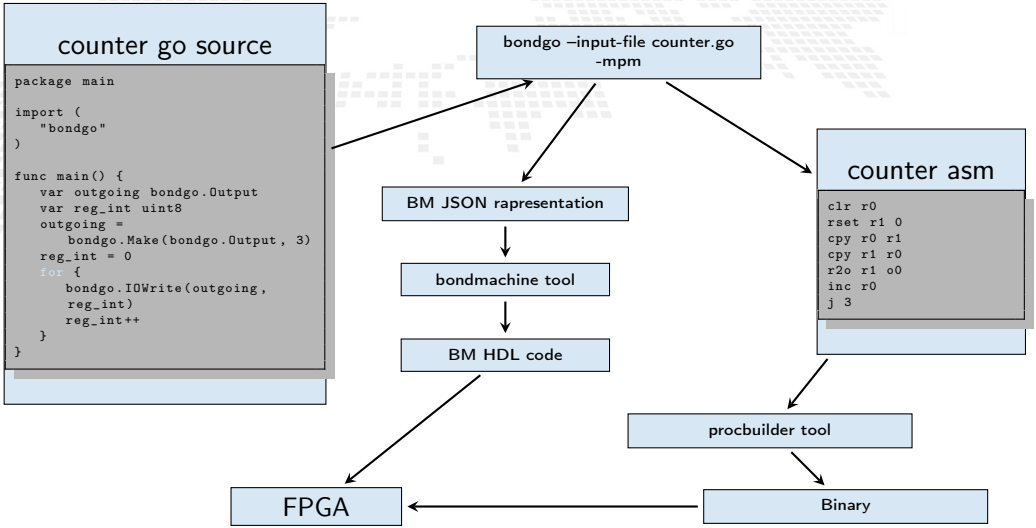

Bondgo

... *bondgo* may not only create the binaries, but also the CP architecture, and ...

Bondgo

... it can do even much more interesting things when compiling concurrent programs.

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high level GO source

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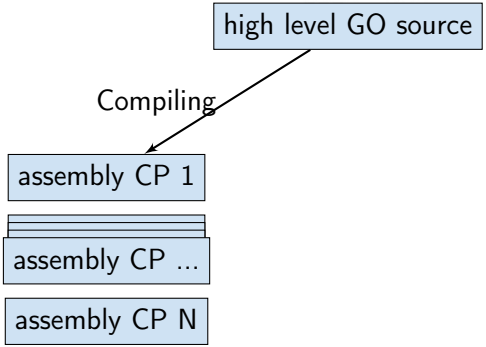

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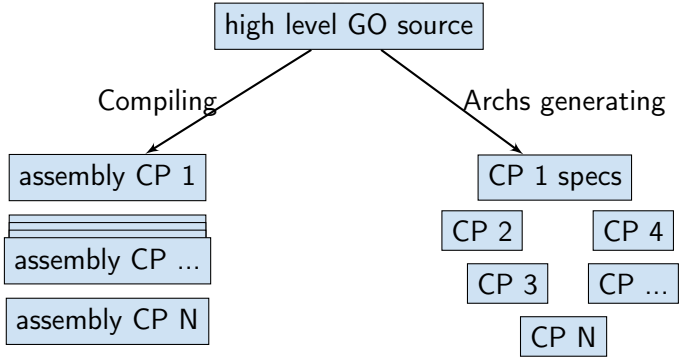

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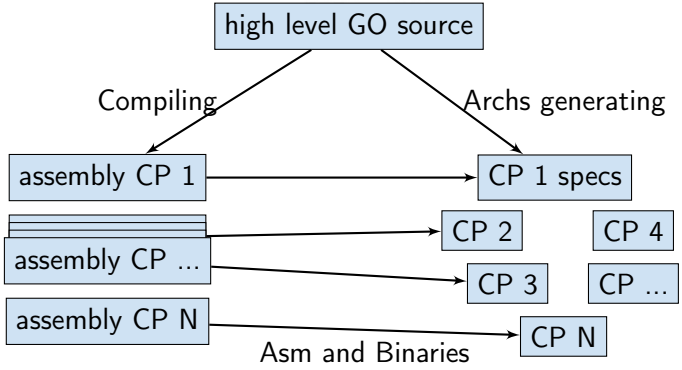

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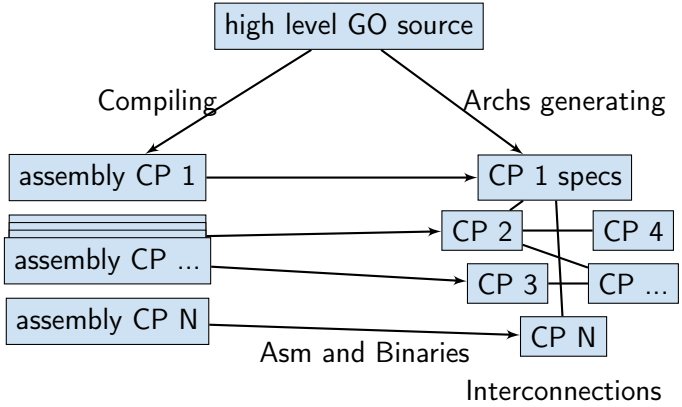

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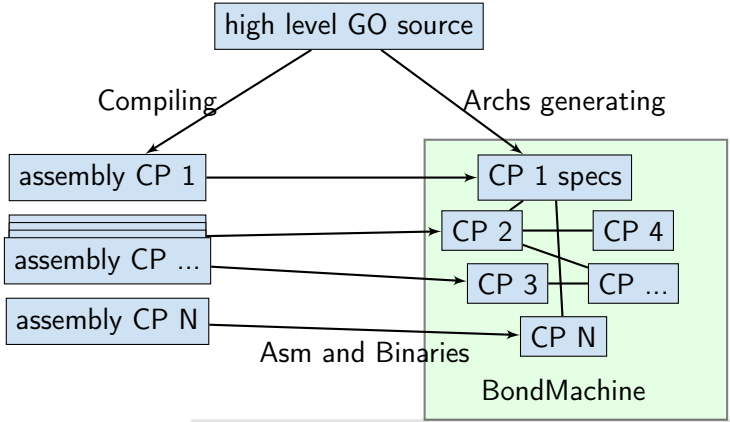


Bondgo

A multi-core example

multi-core counter

```
package main

import (
   "bondgo"
)

func pong() {
   var in0 bondgo.Input
   var out0 bondgo.Output
   in0 = bondgo.Make(bondgo.Input, 3)
   out0 = bondgo.Make(bondgo.Output, 5)
   for {
      bondgo.IOWrite(out0, bondgo.IORead(in0)+1)
   }
}

func main() {
   var in0 bondgo.Input
   var out0 bondgo.Output
   in0 = bondgo.Make(bondgo.Input, 5)
   out0 = bondgo.Make(bondgo.Output, 3)
device_0:
   go pong()
   for {
      bondgo.IOWrite(out0, bondgo.IORead(in0))
   }
}
```

Bondgo

A multi-core example

Compiling the code with the bondgo compiler:

bondgo -input-file ds.go -mpm

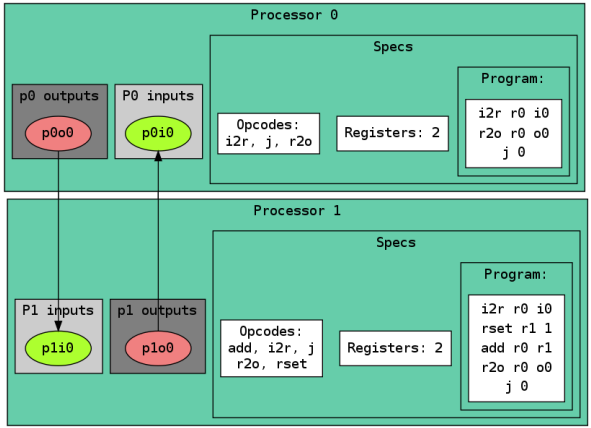
The toolchain perform the following steps:

- Map the two goroutines to two hardware cores.
- Creates two types of core, each one optimized to execute the assigned goroutine.
- Creates the two binaries.
- Connected the two core as inferred from the source code, using special IO registers.

The result is a multicore BondMachine:

Bondgo

A multi-core example



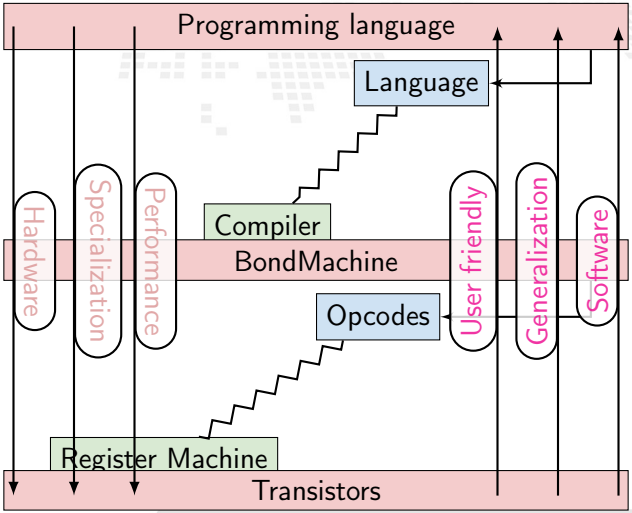
Compiling Architectures

One of the most important result

The architecture creation is a part of the compilation process.

Layers, Abstractions and Interfaces

and BondMachines



Basm

The BondMachine assembler *Basm* is the compiler complementary tools.

The BondMachine "fluid" nature gives the assembler some unique features:

- Support for template based assembly code
- Combining and rewriting fragments of assembly code
- Building hardware from assembly
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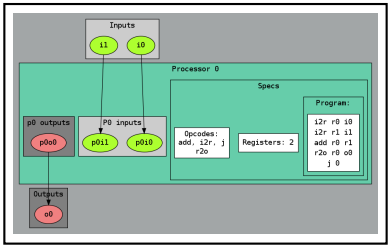
Abstract Assembly

The Assembly language for the BM has been kept as independent as possible from the particular CP.

Given a specific piece of assembly code Bondgo has the ability to compute the "minimum CP" that can execute that code.

```
i2r r0 i0
i2r r1 i1
add r0 r1
r2o r0 o0
   j 0
```



These are Building Blocks for complex BondMachines.

Builders API

With these Building Blocks

Several libraries have been developed to map specific problems on BondMachines:

- Symbond, to handle mathematical expression.
- Boolbond, to map boolean expression.
- Matrixwork, to perform matrices operations.

more about these tools

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BondMachine Clustering

So far we saw:

- An user friendly approach to create processors (single core).
- Optimizing a single device to support intricate computational work-flows (multi-cores) over an heterogeneous layer.

Interconnected BondMachines

What if we could extend the this layer to multiple interconnected devices ?

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Protocols, one ethernet called *etherbond* and one using UDP called *udpbond* have been created for the purpose.

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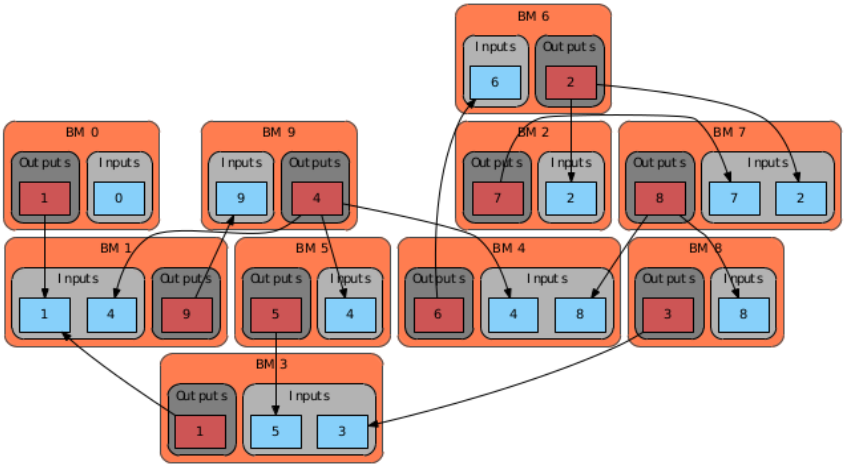

BondMachine Clustering

A distributed example

distributed counter

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   var in0 bondgo.Input
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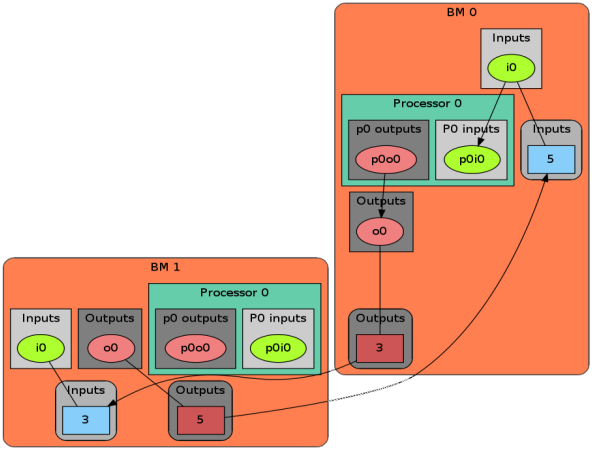
   in0 = bondgo.Make(bondgo.Input, 3)
   out0 = bondgo.Make(bondgo.Output, 5)
   for {
      bondgo.IOWrite(out0, bondgo.IORead(in0)+1)
   }
}

func main() {
   var in0 bondgo.Input
   var out0 bondgo.Output
   in0 = bondgo.Make(bondgo.Input, 5)
   out0 = bondgo.Make(bondgo.Output, 3)
device_1:
   go pong()
   for {
      bondgo.IOWrite(out0, bondgo.IORead(in0))
   }
}
```

BondMachine Clustering

A distributed example



BondMachine Clustering

A distributed example

See it working:
`https://youtube.com/embed/g9xYHK0zca4`

A general result

Parts of the system can be redeployed among different devices without changing the system behavior (only the performances).

BondMachine Clustering

Results

Results

- User can deploy an entire HW/SW cluster starting from code written in a high level description (Go, NNEF, etc)
- Workstation with emulated BondMachines, workstation with etherbond drivers, standalone BondMachines (FPGA) may join these clusters.

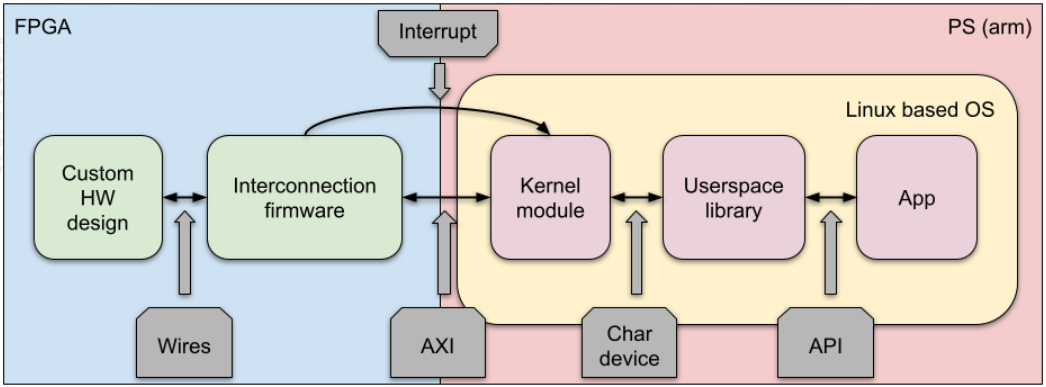
BondMachine Clustering

Results

Results

- User can deploy an entire HW/SW cluster starting from code written in a high level description (Go, NNEF, etc)
- Workstation with emulated BondMachines, workstation with etherbond drivers, standalone BondMachines (FPGA) may join these clusters.

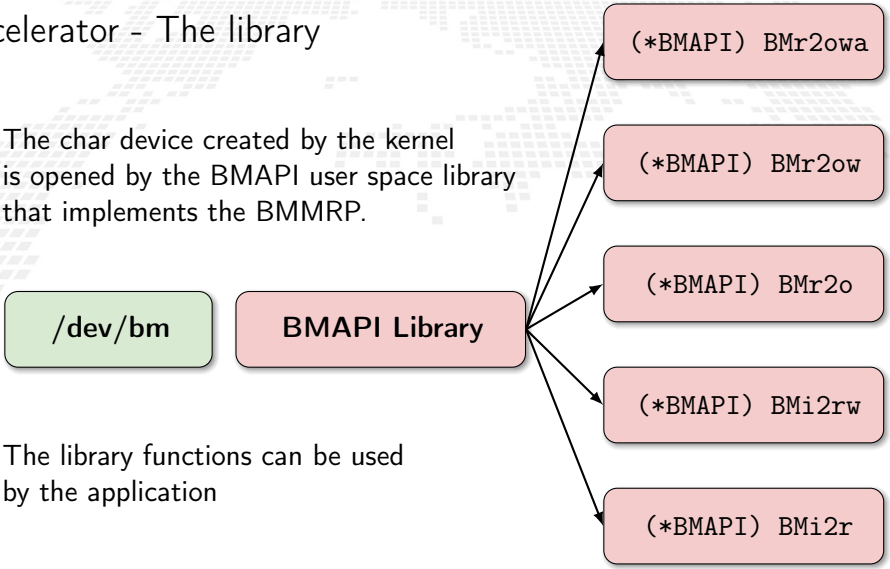
BondMachine as accelerators



Talk with details about how the accelerator is build

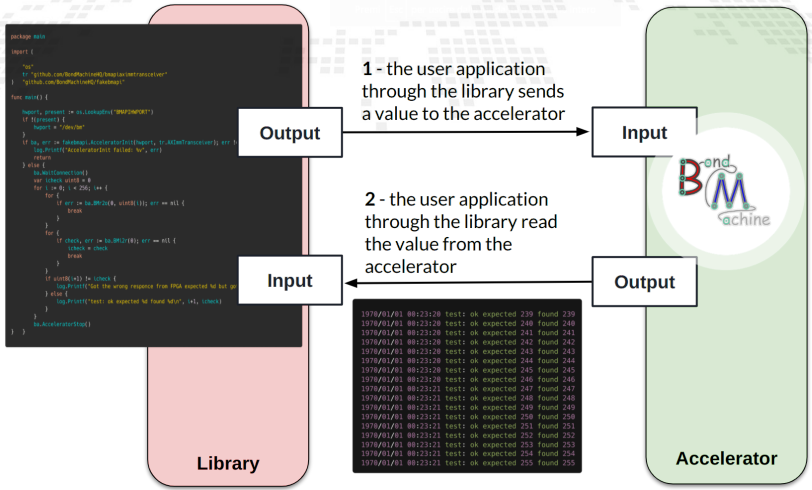
Accelerator - The library

The char device created by the kernel is opened by the BMAPI user space library that implements the BMMRP.



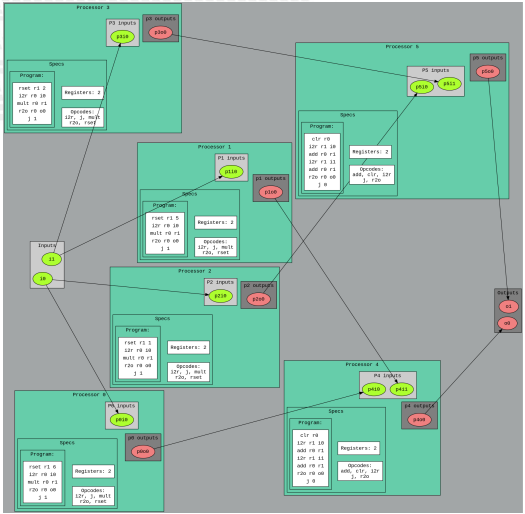
The library functions can be used by the application

Accelerator - The application



BondMachine recap

- The BondMachine is a software ecosystem for the dynamical generation (from several HL types of origin) of computer architectures that can be synthesized of FPGA and
- used as standalone devices,
- as clustered devices,
- and as firmware for computing accelerators.



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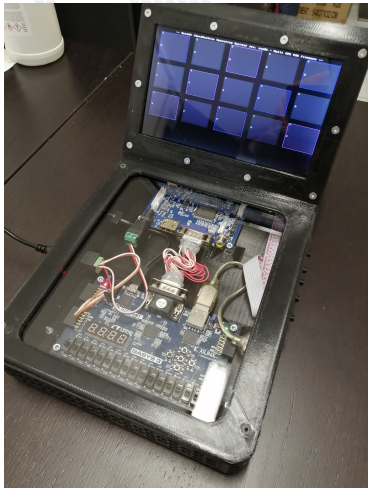

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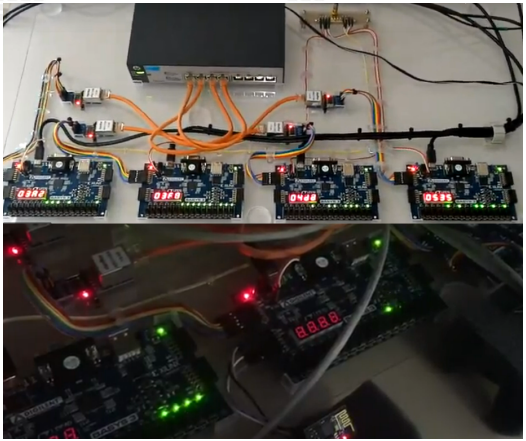

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- CCR 2015 First ideas, 2016 Poster, 2017 Talk
- InnovateFPGA 2018 Iron Award, Grand Final at Intel Campus (CA) USA
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- Invited lectures at: "NiPS Summer School 2019 – Architectures and Algorithms for Energy-Efficient IoT and HPC Applications"
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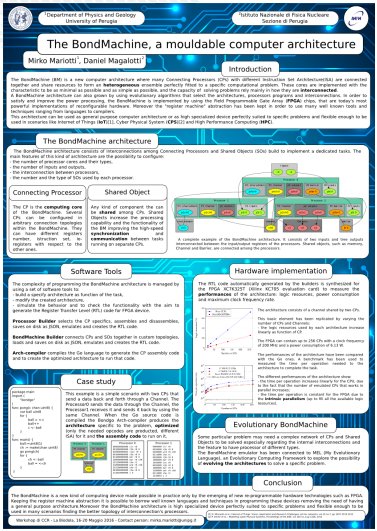
- Article published on Parallel Computing, Elsevier 2022
- PON PHD program



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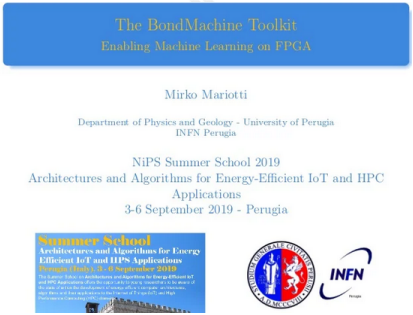

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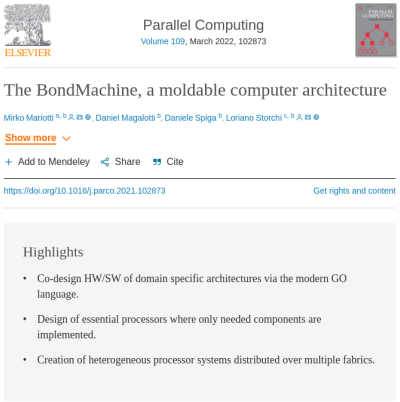

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Parallel Computing

Volume 109, March 2022, 102873

The BondMachine, a moldable computer architecture

Mirko Mariotti [a, b], Daniel Magalotti [b], Daniele Spiga [b], Loriano Storchi [c, b]

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Highlights

- Co-design HW/SW of domain specific architectures via the modern GO language.
- Design of essential processors where only needed components are implemented.
- Creation of heterogeneous processor systems distributed over multiple fabrics.

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- PON PHD program

Fabrics

The HDL code for the BondMachine has been tested on these devices/system:

- Digilent Basys3 - Xilinx Artix-7 - Vivado
- Kintex7 Evaluation Board - Vivado
- Digilent Zedboard - Xilinx Zynq 7020 - Vivado
- ZC702 - Xilinx Zynq 7020 - Vivado
- ebaz4205 - Xilinx Zynq 7020 - Vivado
- Linux - Iverilog
- ice40lp1k icefun icebreaker icesugarnano - Lattice - Icestorm
- Terasic De10nano - Intel Cyclone V - Quartus
- Arrow Max1000 - Intel Max10 - Quartus

Within the project other firmware have been written or tested:

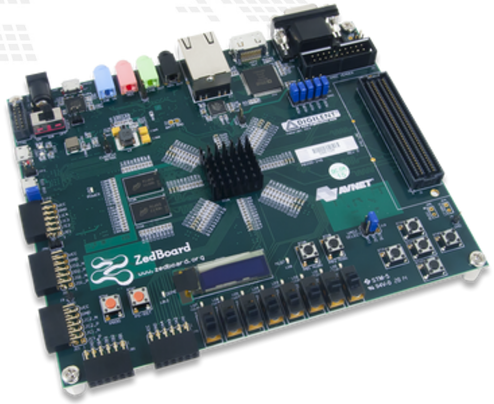
- Microchip ENC28J60 Ethernet interface controller.
- Microchip ENC424J600 10/100 Base-T Ethernet interface controller.
- ESP8266 Wi-Fi chip.

Machine Learning with the BondMachine

Specs

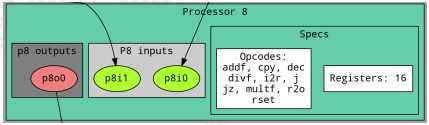
FPGA

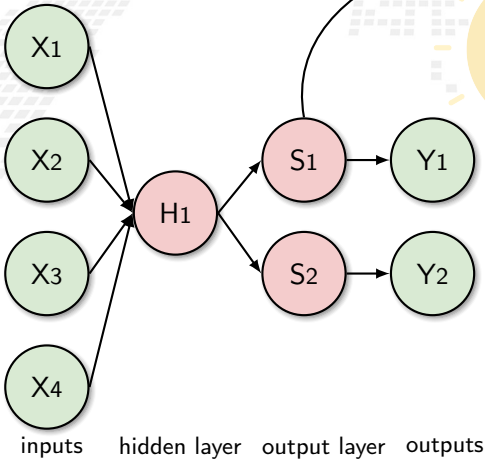
- Digilent Zedboard
- Soc: Zynq XC7Z020-CLG484-1
- 512 MB DDR3
- Vivado 2020.2
- 100MHz
- PYNQ 2.6 (custom build)



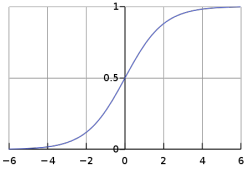
BM inference: A first tentative idea

A neuron of a neural network
can be seen as Connecting Processor of BM





$$\sigma(\vec{z})_i = \frac{e^{z_i}}{\sum_{j=1}^{K} e^{z_j}}$$



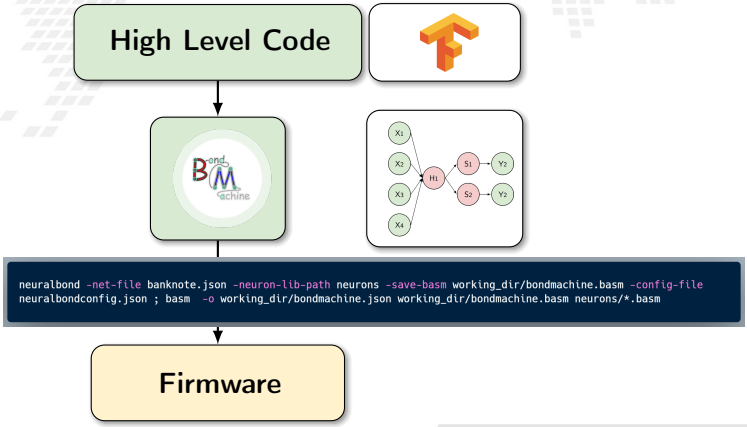

```
%section softmax .romtext iomode:sync
        entry _start    ; Entry point
_start:
 mov r8, 0f0.0
{{range $y := intRange "0" .Params.inputs}}
{{printf "i2r r1,%d\n" $y}}
        mov     r0, 0f1.0
        mov     r2, 0f1.0
        mov     r3, 0f1.0
        mov     r4, 0f1.0
        mov     r5, 0f1.0
        mov     r7, {{$.Params.expprec}}
loop{{printf "%d" $y}}:
        multf   r2, r1
        multf   r3, r4
        addf    r4, r5
        mov     r6, r2
        divf    r6, r3

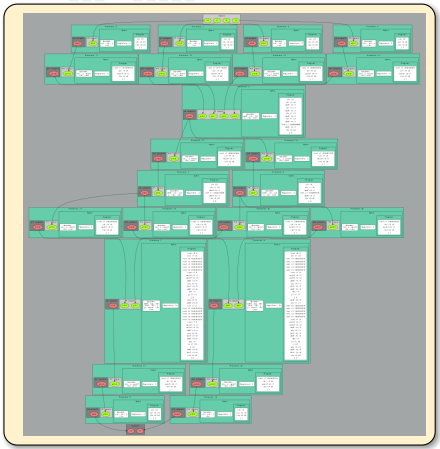
        addf    r0, r6

        dec     r7
        jz      r7,exit{{printf "%d" $y}}
        j       loop{{printf "%d" $y}}
exit{{printf "%d" $y}}:
{{$z := atoi $.Params.pos}}
{{if eq $y $z}}
 mov r9, r0
%endsection
```

From idea to implementation

Starting from High Level Code, a NN model trained with **TensorFlow** and exported in a standard interpreted by **neuralbond** that converts nodes and weights of the network into a set of heterogeneous processors.





A first test

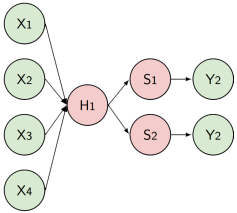
Dataset info:

- **Dataset name**: Banknote Authentication
- **Description**: Dataset on the distinction between genuine and counterfeit banknotes. The data was extracted from images taken from genuine and fake banknote-like samples.
- **N. features**: 4
- **Classification**: binary
- **Samples**: 1097

Neural network info:

- **Class**: Multilayer perceptron fully connected
- **Layers**:
  1. An hidden layer with 1 **linear** neuron
  2. One output layer with 2 **softmax** neurons

Graphic representation:



Demo - Train the model

Demo - Train the model

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```
[ Command > mkdir Example
[ Command > cd Example
[ Command > git clone https://github.com/BondMachineHQ/ml-zedboard.git
cd ml-zedboard
```

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[ Command > mkdir Example
[ Command > cd Example
[ Command > git clone https://github.com/BondMachineHQ/ml-zedboard.git
cd ml-zedboard
[ Output  >
Cloning into 'ml-zedboard'...
remote: Enumerating objects: 103, done.
remote: Counting objects: 100% (103/103), done.
remote: Compressing objects: 100% (65/65), done.
remote: Total 103 (delta 38), reused 95 (delta 30), pack-reused 0
Receiving objects: 100% (103/103), 2.70 MiB | 6.33 MiB/s, done.
Resolving deltas: 100% (38/38), done.
```

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[ Command > ls -al
[ Output  >
total 69
drwx------ 8 mirko users    18 Nov  3 23:20 .
drwx------ 3 mirko users     3 Nov  3 23:20 ..
drwx------ 7 mirko users    12 Nov  3 23:20 .git
-rw------- 1 mirko users  9548 Nov  3 23:20 README.md
-rwx------ 1 mirko users    25 Nov  3 23:20 activate_environment.sh
-rw------- 1 mirko users  5818 Nov  3 23:20 analyze.py
-rw------- 1 mirko users  7515 Nov  3 23:20 analyze_output.py
-rw------- 1 mirko users 18799 Nov  3 23:20 bmtrain.py
drwx------ 2 mirko users    11 Nov  3 23:20 images
-rw------- 1 mirko users  2229 Nov  3 23:20 main.py
drwx------ 2 mirko users     3 Nov  3 23:20 notebooks
drwx------ 3 mirko users     3 Nov  3 23:20 outputs
drwx------ 4 mirko users     4 Nov  3 23:20 reports
-rw------- 1 mirko users    69 Nov  3 23:20 requirements.txt
drwx------ 2 mirko users     4 Nov  3 23:20 resources
-rwx------ 1 mirko users    43 Nov  3 23:20 setup_enviroment.sh
-rw------- 1 mirko users   519 Nov  3 23:20 specifics.json
-rw------- 1 mirko users   559 Nov  3 23:20 utils.txt
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-rw------- 1 mirko users   519 Nov  3 23:20 specifics.json
-rw------- 1 mirko users   559 Nov  3 23:20 utils.txt
[ Command > conda create --name ml-zedboard -y python==3.8.0
```

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```
  libstdcxx-ng       pkgs/main/linux-64::libstdcxx-ng-11.2.0-h1234567_1 None
  ncurses            pkgs/main/linux-64::ncurses-6.3-h5eee18b_3 None
  openssl            pkgs/main/linux-64::openssl-1.1.1q-h7f8727e_0 None
  pip                pkgs/main/linux-64::pip-22.2.2-py38h06a4308_0 None
  python             pkgs/main/linux-64::python-3.8.0-h0371630_2 None
  readline           pkgs/main/linux-64::readline-7.0-h7b6447c_5 None
  setuptools         pkgs/main/linux-64::setuptools-65.5.0-py38h06a4308_0 None
  sqlite             pkgs/main/linux-64::sqlite-3.33.0-h62c20be_0 None
  tk                 pkgs/main/linux-64::tk-8.6.12-h1ccaba5_0 None
  wheel              pkgs/main/noarch::wheel-0.37.1-pyhd3eb1b0_0 None
  xz                 pkgs/main/linux-64::xz-5.2.6-h5eee18b_0 None
  zlib               pkgs/main/linux-64::zlib-1.2.13-h5eee18b_0 None


Preparing transaction: done
Verifying transaction: done
Executing transaction: done
#
# To activate this environment, use
#
#     $ conda activate ml-zedboard
#
# To deactivate an active environment, use
#
#     $ conda deactivate

Retrieving notices: ...working... done
```

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```
  ncurses           pkgs/main/linux-64::ncurses-6.3-h5eee18b_3 None
  openssl           pkgs/main/linux-64::openssl-1.1.1q-h7f8727e_0 None
  pip               pkgs/main/linux-64::pip-22.2.2-py38h06a4308_0 None
  python            pkgs/main/linux-64::python-3.8.0-h0371630_2 None
  readline          pkgs/main/linux-64::readline-7.0-h7b6447c_5 None
  setuptools        pkgs/main/linux-64::setuptools-65.5.0-py38h06a4308_0 None
  sqlite            pkgs/main/linux-64::sqlite-3.33.0-h62c20be_0 None
  tk                pkgs/main/linux-64::tk-8.6.12-h1ccaba5_0 None
  wheel             pkgs/main/noarch::wheel-0.37.1-pyhd3eb1b0_0 None
  xz                pkgs/main/linux-64::xz-5.2.6-h5eee18b_0 None
  zlib              pkgs/main/linux-64::zlib-1.2.13-h5eee18b_0 None


Preparing transaction: done
Verifying transaction: done
Executing transaction: done
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#
# To deactivate an active environment, use
#
#     $ conda deactivate

Retrieving notices: ...working... done
[ Command > conda activate ml-zedboard
```

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```
  ncurses           pkgs/main/linux-64::ncurses-6.3-h5eee18b_3 None
  openssl           pkgs/main/linux-64::openssl-1.1.1q-h7f8727e_0 None
  pip               pkgs/main/linux-64::pip-22.2.2-py38h06a4308_0 None
  python            pkgs/main/linux-64::python-3.8.0-h0371630_2 None
  readline          pkgs/main/linux-64::readline-7.0-h7b6447c_5 None
  setuptools        pkgs/main/linux-64::setuptools-65.5.0-py38h06a4308_0 None
  sqlite            pkgs/main/linux-64::sqlite-3.33.0-h62c20be_0 None
  tk                pkgs/main/linux-64::tk-8.6.12-h1ccaba5_0 None
  wheel             pkgs/main/noarch::wheel-0.37.1-pyhd3eb1b0_0 None
  xz                pkgs/main/linux-64::xz-5.2.6-h5eee18b_0 None
  zlib              pkgs/main/linux-64::zlib-1.2.13-h5eee18b_0 None


Preparing transaction: done
Verifying transaction: done
Executing transaction: done
#
# To activate this environment, use
#
#     $ conda activate ml-zedboard
#
# To deactivate an active environment, use
#
#     $ conda deactivate

Retrieving notices: ...working... done
[ Command > conda activate ml-zedboard
```

Demo - Train the model

```
  openssl           pkgs/main/linux-64::openssl-1.1.1q-h7f8727e_0 None
  pip               pkgs/main/linux-64::pip-22.2.2-py38h06a4308_0 None
  python            pkgs/main/linux-64::python-3.8.0-h0371630_2 None
  readline          pkgs/main/linux-64::readline-7.0-h7b6447c_5 None
  setuptools        pkgs/main/linux-64::setuptools-65.5.0-py38h06a4308_0 None
  sqlite            pkgs/main/linux-64::sqlite-3.33.0-h62c20be_0 None
  tk                pkgs/main/linux-64::tk-8.6.12-h1ccaba5_0 None
  wheel             pkgs/main/noarch::wheel-0.37.1-pyhd3eb1b0_0 None
  xz                pkgs/main/linux-64::xz-5.2.6-h5eee18b_0 None
  zlib              pkgs/main/linux-64::zlib-1.2.13-h5eee18b_0 None


Preparing transaction: done
Verifying transaction: done
Executing transaction: done
#
# To activate this environment, use
#
#     $ conda activate ml-zedboard
#
# To deactivate an active environment, use
#
#     $ conda deactivate

Retrieving notices: ...working... done
[ Command > conda activate ml-zedboard
[ Command > pip3 install -r requirements.txt
```

Demo - Train the model

```
Collecting MarkupSafe>=2.1.1
  Using cached MarkupSafe-2.1.1-cp38-cp38-manylinux_2_17_x86_64.manylinux2014_x86_64.whl (25 kB)
Collecting zipp>=0.5
  Using cached zipp-3.10.0-py3-none-any.whl (6.2 kB)
Collecting pyasn1<0.5.0,>=0.4.6
  Using cached pyasn1-0.4.8-py2.py3-none-any.whl (77 kB)
Collecting oauthlib>=3.0.0
  Using cached oauthlib-3.2.2-py3-none-any.whl (151 kB)
Installing collected packages: tensorboard-plugin-wit, pytz, pyasn1, libclang, keras, flatbuffers, z
ipp, xlrd, wrapt, urllib3, typing-extensions, threadpoolctl, termcolor, tensorflow-io-gcs-filesystem
, tensorflow-estimator, tensorboard-data-server, six, rsa, pyyaml, pyparsing, pyasn1-modules, protob
uf, pillow, oauthlib, numpy, networkx, MarkupSafe, kiwisolver, joblib, idna, gast, fonttools, cycler
, charset-normalizer, cachetools, absl-py, werkzeug, scipy, requests, python-dateutil, pydot, packag
ing, opt-einsum, onnx, keras-preprocessing, importlib-metadata, h5py, grpcio, google-pasta, google-a
uth, contourpy, astunparse, scikit-learn, requests-oauthlib, pandas, matplotlib, markdown, hls4ml, s
klearn, google-auth-oauthlib, tensorboard, tensorflow
Successfully installed MarkupSafe-2.1.1 absl-py-1.3.0 astunparse-1.6.3 cachetools-5.2.0 charset-norm
alizer-2.1.1 contourpy-1.0.6 cycler-0.11.0 flatbuffers-22.10.26 fonttools-4.38.0 gast-0.4.0 google-a
uth-2.14.0 google-auth-oauthlib-0.4.6 google-pasta-0.2.0 grpcio-1.50.0 h5py-3.7.0 hls4ml-0.6.0 idna-
3.4 importlib-metadata-5.0.0 joblib-1.2.0 keras-2.10.0 keras-preprocessing-1.1.2 kiwisolver-1.4.4 li
bclang-14.0.6 markdown-3.4.1 matplotlib-3.6.2 networkx-2.8.8 numpy-1.23.4 oauthlib-3.2.2 onnx-1.12.0
 opt-einsum-3.3.0 packaging-21.3 pandas-1.5.1 pillow-9.3.0 protobuf-3.19.6 pyasn1-0.4.8 pyasn1-modul
es-0.2.8 pydot-1.4.2 pyparsing-3.0.9 python-dateutil-2.8.2 pytz-2022.6 pyyaml-6.0 requests-2.28.1 re
quests-oauthlib-1.3.1 rsa-4.9 scikit-learn-1.1.3 scipy-1.9.3 six-1.16.0 sklearn-0.0 tensorboard-2.10
.1 tensorboard-data-server-0.6.1 tensorboard-plugin-wit-1.8.1 tensorflow-2.10.0 tensorflow-estimator
-2.10.0 tensorflow-io-gcs-filesystem-0.27.0 termcolor-2.1.0 threadpoolctl-3.1.0 typing-extensions-4.
4.0 urllib3-1.26.12 werkzeug-2.2.2 wrapt-1.14.1 xlrd-2.0.1 zipp-3.10.0
```

Demo - Train the model

```
  Using cached MarkupSafe-2.1.1-cp38-cp38-manylinux_2_17_x86_64.manylinux2014_x86_64.whl (25 kB)
Collecting zipp>=0.5
  Using cached zipp-3.10.0-py3-none-any.whl (6.2 kB)
Collecting pyasn1<0.5.0,>=0.4.6
  Using cached pyasn1-0.4.8-py2.py3-none-any.whl (77 kB)
Collecting oauthlib>=3.0.0
  Using cached oauthlib-3.2.2-py3-none-any.whl (151 kB)
Installing collected packages: tensorboard-plugin-wit, pytz, pyasn1, libclang, keras, flatbuffers, z
ipp, xlrd, wrapt, urllib3, typing-extensions, threadpoolctl, termcolor, tensorflow-io-gcs-filesystem
, tensorflow-estimator, tensorboard-data-server, six, rsa, pyyaml, pyparsing, pyasn1-modules, protob
uf, pillow, oauthlib, numpy, networkx, MarkupSafe, kiwisolver, joblib, idna, gast, fonttools, cycler
, charset-normalizer, cachetools, absl-py, werkzeug, scipy, requests, python-dateutil, pydot, packag
ing, opt-einsum, onnx, keras-preprocessing, importlib-metadata, h5py, grpcio, google-pasta, google-a
uth, contourpy, astunparse, scikit-learn, requests-oauthlib, pandas, matplotlib, markdown, hls4ml, s
klearn, google-auth-oauthlib, tensorboard, tensorflow
Successfully installed MarkupSafe-2.1.1 absl-py-1.3.0 astunparse-1.6.3 cachetools-5.2.0 charset-norm
alizer-2.1.1 contourpy-1.0.6 cycler-0.11.0 flatbuffers-22.10.26 fonttools-4.38.0 gast-0.4.0 google-a
uth-2.14.0 google-auth-oauthlib-0.4.6 google-pasta-0.2.0 grpcio-1.50.0 h5py-3.7.0 hls4ml-0.6.0 idna-
3.4 importlib-metadata-5.0.0 joblib-1.2.0 keras-2.10.0 keras-preprocessing-1.1.2 kiwisolver-1.4.4 li
bclang-14.0.6 markdown-3.4.1 matplotlib-3.6.2 networkx-2.8.8 numpy-1.23.4 oauthlib-3.2.2 onnx-1.12.0
 opt-einsum-3.3.0 packaging-21.3 pandas-1.5.1 pillow-9.3.0 protobuf-3.19.6 pyasn1-0.4.8 pyasn1-modul
es-0.2.8 pydot-1.4.2 pyparsing-3.0.9 python-dateutil-2.8.2 pytz-2022.6 pyyaml-6.0 requests-2.28.1 re
quests-oauthlib-1.3.1 rsa-4.9 scikit-learn-1.1.3 scipy-1.9.3 six-1.16.0 sklearn-0.0 tensorboard-2.10
.1 tensorboard-data-server-0.6.1 tensorboard-plugin-wit-1.8.1 tensorflow-2.10.0 tensorflow-estimator
-2.10.0 tensorflow-io-gcs-filesystem-0.27.0 termcolor-2.1.0 threadpoolctl-3.1.0 typing-extensions-4.
4.0 urllib3-1.26.12 werkzeug-2.2.2 wrapt-1.14.1 xlrd-2.0.1 zipp-3.10.0
[ Command > ls -al main.py bmtrain.py banknote-authentication*
```

Demo - Train the model

```
  Using cached pyasn1-0.4.8-py2.py3-none-any.whl (77 kB)
Collecting oauthlib>=3.0.0
  Using cached oauthlib-3.2.2-py3-none-any.whl (151 kB)
Installing collected packages: tensorboard-plugin-wit, pytz, pyasn1, libclang, keras, flatbuffers, z
ipp, xlrd, wrapt, urllib3, typing-extensions, threadpoolctl, termcolor, tensorflow-io-gcs-filesystem
, tensorflow-estimator, tensorboard-data-server, six, rsa, pyyaml, pyparsing, pyasn1-modules, protob
uf, pillow, oauthlib, numpy, networkx, MarkupSafe, kiwisolver, joblib, idna, gast, fonttools, cycler
, charset-normalizer, cachetools, absl-py, werkzeug, scipy, requests, python-dateutil, pydot, packag
ing, opt-einsum, onnx, keras-preprocessing, importlib-metadata, h5py, grpcio, google-pasta, google-a
uth, contourpy, astunparse, scikit-learn, requests-oauthlib, pandas, matplotlib, markdown, hls4ml, s
klearn, google-auth-oauthlib, tensorboard, tensorflow
Successfully installed MarkupSafe-2.1.1 absl-py-1.3.0 astunparse-1.6.3 cachetools-5.2.0 charset-norm
alizer-2.1.1 contourpy-1.0.6 cycler-0.11.0 flatbuffers-22.10.26 fonttools-4.38.0 gast-0.4.0 google-a
uth-2.14.0 google-auth-oauthlib-0.4.6 google-pasta-0.2.0 grpcio-1.50.0 h5py-3.7.0 hls4ml-0.6.0 idna-
3.4 importlib-metadata-5.0.0 joblib-1.2.0 keras-2.10.0 keras-preprocessing-1.1.2 kiwisolver-1.4.4 li
bclang-14.0.6 markdown-3.4.1 matplotlib-3.6.2 networkx-2.8.8 numpy-1.23.4 oauthlib-3.2.2 onnx-1.12.0
 opt-einsum-3.3.0 packaging-21.3 pandas-1.5.1 pillow-9.3.0 protobuf-3.19.6 pyasn1-0.4.8 pyasn1-modul
es-0.2.8 pydot-1.4.2 pyparsing-3.0.9 python-dateutil-2.8.2 pytz-2022.6 pyyaml-6.0 requests-2.28.1 re
quests-oauthlib-1.3.1 rsa-4.9 scikit-learn-1.1.3 scipy-1.9.3 six-1.16.0 sklearn-0.0 tensorboard-2.10
.1 tensorboard-data-server-0.6.1 tensorboard-plugin-wit-1.8.1 tensorflow-2.10.0 tensorflow-estimator
-2.10.0 tensorflow-io-gcs-filesystem-0.27.0 termcolor-2.1.0 threadpoolctl-3.1.0 typing-extensions-4.
4.0 urllib3-1.26.12 werkzeug-2.2.2 wrapt-1.14.1 xlrd-2.0.1 zipp-3.10.0
[ Command > ls -al main.py bmtrain.py banknote-authentication*
[ Output  >
ls: cannot access 'banknote-authentication*': No such file or directory
-rw------- 1 mirko users 18799 Nov  3 23:20  bmtrain.py
-rw------- 1 mirko users  2229 Nov  3 23:20  main.py
```

Demo - Train the model

```
Installing collected packages: tensorboard-plugin-wit, pytz, pyasn1, libclang, keras, flatbuffers, z
ipp, xlrd, wrapt, urllib3, typing-extensions, threadpoolctl, termcolor, tensorflow-io-gcs-filesystem
, tensorflow-estimator, tensorboard-data-server, six, rsa, pyyaml, pyparsing, pyasn1-modules, protob
uf, pillow, oauthlib, numpy, networkx, MarkupSafe, kiwisolver, joblib, idna, gast, fonttools, cycler
, charset-normalizer, cachetools, absl-py, werkzeug, scipy, requests, python-dateutil, pydot, packag
ing, opt-einsum, onnx, keras-preprocessing, importlib-metadata, h5py, grpcio, google-pasta, google-a
uth, contourpy, astunparse, scikit-learn, requests-oauthlib, pandas, matplotlib, markdown, hls4ml, s
klearn, google-auth-oauthlib, tensorboard, tensorflow
Successfully installed MarkupSafe-2.1.1 absl-py-1.3.0 astunparse-1.6.3 cachetools-5.2.0 charset-norm
alizer-2.1.1 contourpy-1.0.6 cycler-0.11.0 flatbuffers-22.10.26 fonttools-4.38.0 gast-0.4.0 google-a
uth-2.14.0 google-auth-oauthlib-0.4.6 google-pasta-0.2.0 grpcio-1.50.0 h5py-3.7.0 hls4ml-0.6.0 idna-
3.4 importlib-metadata-5.0.0 joblib-1.2.0 keras-2.10.0 keras-preprocessing-1.1.2 kiwisolver-1.4.4 li
bclang-14.0.6 markdown-3.4.1 matplotlib-3.6.2 networkx-2.8.8 numpy-1.23.4 oauthlib-3.2.2 onnx-1.12.0
 opt-einsum-3.3.0 packaging-21.3 pandas-1.5.1 pillow-9.3.0 protobuf-3.19.6 pyasn1-0.4.8 pyasn1-modul
es-0.2.8 pydot-1.4.2 pyparsing-3.0.9 python-dateutil-2.8.2 pytz-2022.6 pyyaml-6.0 requests-2.28.1 re
quests-oauthlib-1.3.1 rsa-4.9 scikit-learn-1.1.3 scipy-1.9.3 six-1.16.0 sklearn-0.0 tensorboard-2.10
.1 tensorboard-data-server-0.6.1 tensorboard-plugin-wit-1.8.1 tensorflow-2.10.0 tensorflow-estimator
-2.10.0 tensorflow-io-gcs-filesystem-0.27.0 termcolor-2.1.0 threadpoolctl-3.1.0 typing-extensions-4.
4.0 urllib3-1.26.12 werkzeug-2.2.2 wrapt-1.14.1 xlrd-2.0.1 zipp-3.10.0
[ Command > ls -al main.py bmtrain.py banknote-authentication*
[ Output  >
ls: cannot access 'banknote-authentication*': No such file or directory
-rw------- 1 mirko users 18799 Nov  3 23:20  bmtrain.py
-rw------- 1 mirko users  2229 Nov  3 23:20  main.py
[ Command >
export PYTHONPATH=/tmp/tmptj5_gk0p/Example/ml-zedboard
python-inspect -m bmtrain -o build_model 2> /dev/null | pygmentize -l python | head -n 20
```

Demo - Train the model

```
[ Command ]
export PYTHONPATH=/tmp/tmptj5_gk0p/Example/ml-zedboard
python-inspect -m bmtrain -o build_model 2> /dev/null | pygmentize -l python | head -n 20
[ Output  ]
    def build_model(self):
        if self.nn_model_type == "MLP":

            self.model = Sequential()

            self.parse_network_specifics()

            if self.network_spec == None:
                for i in range(0, 24, 3):
                    self.model.add(Dense(i, input_shape=(self.X_train_val.shape[1],)))
                for i in reversed(range(0, 24, 3)):
                    self.model.add(Dense(i, input_shape=(self.X_train_val.shape[1],)))
                opt = Adam(lr=0.0001)
            else:
                arch = self.network_spec["network"]["arch"]
                for i in range(0, len(arch)):
                    layer_name = self.network_spec["network"]["arch"][i]["layer_name"]
                    activation_function = self.network_spec["network"]["arch"][i]["activation_functi
on"]
                    neurons = self.network_spec["network"]["arch"][i]["neurons"]
                    if i == 0:
Exception ignored in: <_io.TextIOWrapper name='<stdout>' mode='w' encoding='utf-8'>
BrokenPipeError: [Errno 32] Broken pipe
```

Demo - Train the model

```
    def build_model(self):
        if self.nn_model_type == "MLP":

            self.model = Sequential()

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                    self.model.add(Dense(i, input_shape=(self.X_train_val.shape[1],)))
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            else:
                arch = self.network_spec["network"]["arch"]
                for i in range(0, len(arch)):
                    layer_name = self.network_spec["network"]["arch"][i]["layer_name"]
                    activation_function = self.network_spec["network"]["arch"][i]["activation_functi
on"]

                    neurons = self.network_spec["network"]["arch"][i]["neurons"]
                    if i == 0:
Exception ignored in: <_io.TextIOWrapper name='<stdout>' mode='w' encoding='utf-8'>
BrokenPipeError: [Errno 32] Broken pipe
[ Command >
export PYTHONPATH=/tmp/tmptj5_gk0p/Example/ml-zedboard
python-inspect -m bmtrain -o dump_json_for_bondmachine 2> /dev/null | pygmentize -l python | head -n
 20
```

Demo - Train the model

```
[ Command ]
export PYTHONPATH=/tmp/tmptj5_gk0p/Example/ml-zedboard
python-inspect -m bmtrain -o dump_json_for_bondmachine 2> /dev/null | pygmentize -l python | head -n
 20
[ Output  ]
    def dump_json_for_bondmachine(self):
        import json

        layers = self.model.layers
        weights = self.model.weights

        to_dump = {}

        weights = []
        nodes = []

        # save weigths
        for i in range(0 , len(layers)):

            layer_weights = layers[i].get_weights()

            for m in range(0, len(layer_weights)):
                for w in range(0, len(layer_weights[m])):
                    try:
                        for v in range(0, len(layer_weights[m][w])):
Exception ignored in: <_io.TextIOWrapper name='<stdout>' mode='w' encoding='utf-8'>
BrokenPipeError: [Errno 32] Broken pipe
```

Demo - Train the model

```
export PYTHONPATH=/tmp/tmptj5_gk0p/Example/ml-zedboard
python-inspect -m bmtrain -o dump_json_for_bondmachine 2> /dev/null | pygmentize -l python | head -n
 20
[ Output  >
    def dump_json_for_bondmachine(self):
        import json

        layers = self.model.layers
        weights = self.model.weights

        to_dump = {}

        weights = []
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        # save weigths
        for i in range(0 , len(layers)):

            layer_weights = layers[i].get_weights()

            for m in range(0, len(layer_weights)):
                for w in range(0, len(layer_weights[m])):
                    try:
                        for v in range(0, len(layer_weights[m][w])):
Exception ignored in: <_io.TextIOWrapper name='<stdout>' mode='w' encoding='utf-8'>
BrokenPipeError: [Errno 32] Broken pipe
[ Command > python3 main.py --dataset banknote-authentication -m MLP
```

Demo - Train the model

```
822/822 [==============================] - 0s 37us/sample - loss: 0.4611 - acc: 0.9599 - val_loss: 0
.4695 - val_acc: 0.9636
 *** dump model
 # INFO: Training finished, saved model path: models/banknote-authentication_KERAS_model.h5
Model: "sequential"
_________________________________________________________________
 Layer (type)                 Output Shape              Param #
=================================================================
 dense (Dense)                (None, 1)                 5

 dense_1 (Dense)              (None, 2)                 4

=================================================================
Total params: 9
Trainable params: 9
Non-trainable params: 0
_________________________________________________________________
None
/tools/Conda/envs/ml-zedboard/lib/python3.8/site-packages/keras/engine/training_v1.py:2356: UserWarn
ing: `Model.state_updates` will be removed in a future version. This property should not be used in
TensorFlow 2.0, as `updates` are applied automatically.
  updates=self.state_updates,
Sofware predicions have been exported in CSV (path is: datasets/banknote-authentication_swprediction
.csv)
 # INFO: Accuracy is 0.9454545454545454
Model has been exported in JSON for Bondmachine (path is: models/banknote-authentication/modelBM.jso
n)
```

Demo - Train the model

```
Model: "sequential"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 dense (Dense)               (None, 1)                 5

 dense_1 (Dense)             (None, 2)                 4

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Sofware predicions have been exported in CSV (path is: datasets/banknote-authentication_swprediction
.csv)
 # INFO: Accuracy is 0.9454545454545454
Model has been exported in JSON for Bondmachine (path is: models/banknote-authentication/modelBM.jso
n)
[ Command >
cp models/banknote-authentication/modelBM.json /tmp/modelBM.json
cp datasets/banknote-authentication_swprediction.csv /tmp/sw.csv
cp datasets/banknote-authentication_sample.csv /tmp/sample.csv
```

Demo - Train the model

```
 Layer (type)                 Output Shape              Param #
=================================================================
 dense (Dense)                (None, 1)                 5

 dense_1 (Dense)              (None, 2)                 4

=================================================================
Total params: 9
Trainable params: 9
Non-trainable params: 0
_________________________________________________________________
None
/tools/Conda/envs/ml-zedboard/lib/python3.8/site-packages/keras/engine/training_v1.py:2356: UserWarn
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Sofware predicions have been exported in CSV (path is: datasets/banknote-authentication_swprediction
.csv)
 # INFO: Accuracy is 0.9454545454545454
Model has been exported in JSON for Bondmachine (path is: models/banknote-authentication/modelBM.jso
n)
[ Command >
cp models/banknote-authentication/modelBM.json /tmp/modelBM.json
cp datasets/banknote-authentication_swprediction.csv /tmp/sw.csv
cp datasets/banknote-authentication_sample.csv /tmp/sample.csv
[ Output  >
```

Demo - Train the model

```
 Layer (type)                 Output Shape              Param #
=================================================================
 dense (Dense)                (None, 1)                 5

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.csv)
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Model has been exported in JSON for Bondmachine (path is: models/banknote-authentication/modelBM.jso
n)
[ Command >
cp models/banknote-authentication/modelBM.json /tmp/modelBM.json
cp datasets/banknote-authentication_swprediction.csv /tmp/sw.csv
cp datasets/banknote-authentication_sample.csv /tmp/sample.csv
[ Output  >
[ Command > conda deactivate ; conda env remove --name ml-zedboard
```

Demo - Train the model

```
 Layer (type)                 Output Shape              Param #
=================================================================
 dense (Dense)                (None, 1)                 5

 dense_1 (Dense)              (None, 2)                 4

=================================================================
Total params: 9
Trainable params: 9
Non-trainable params: 0
_________________________________________________________________
None
/tools/Conda/envs/ml-zedboard/lib/python3.8/site-packages/keras/engine/training_v1.py:2356: UserWarn
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 # INFO: Accuracy is 0.9454545454545454
Model has been exported in JSON for Bondmachine (path is: models/banknote-authentication/modelBM.jso
n)
[ Command >
cp models/banknote-authentication/modelBM.json /tmp/modelBM.json
cp datasets/banknote-authentication_swprediction.csv /tmp/sw.csv
cp datasets/banknote-authentication_sample.csv /tmp/sample.csv
[ Output  >
[ Command > conda deactivate ; conda env remove --name ml-zedboard
```

Project creation

The outcome of this first part of the demo are three files:

- sample.csv is a test dataset that will be used to feed the inferences of both: the BM hardware and the BM simulation
- sw.csv is the software predictions over that dataset and will be used to check the BM inference probabilities and predictions
- modelBM.json is the trained network that will use as BM source in the next demo

DEMO - BondMachine creation

DEMO - BondMachine creation

DEMO - BondMachine creation

DEMO - BondMachine creation

```
[ Command > mkdir Example
[ Command > cd Example
[ Command > bmhelper create --project_name mlinfn --board zedboard --project_type neural_network --n
_inputs 4 --n_outputs 3 --source_neuralbond banknote.json
```

DEMO - BondMachine creation

```
[ Command > mkdir Example
[ Command > cd Example
[ Command > bmhelper create --project_name mlinfn --board zedboard --project_type neural_network --n
_inputs 4 --n_outputs 3 --source_neuralbond banknote.json
```

DEMO - BondMachine creation

```
[ Command > mkdir Example
[ Command > cd Example
[ Command > bmhelper create --project_name mlinfn --board zedboard --project_type neural_network --n
_inputs 4 --n_outputs 3 --source_neuralbond banknote.json
[ Command >
cd proj_mlinfn
ls -al
```

DEMO - BondMachine creation

```
[ Command > bmhelper create --project_name mlinfn --board zedboard --project_type neural_network --n
_inputs 4 --n_outputs 3 --source_neuralbond banknote.json
[ Command >
cd proj_mlinfn
ls -al
[ Output  >
total 10
drwx------ 3 mirko users    20 Nov  2 22:21 .
drwx------ 3 mirko users    17 Nov  2 22:21 ..
-rw------- 1 mirko users 44179 Nov  2 22:21 Makefile
-rw------- 1 mirko users   397 Nov  2 22:21 authorized_keys
-rw------- 1 mirko users  1962 Nov  2 22:21 banknote.json
-rw------- 1 mirko users   150 Nov  2 22:21 bmapi.json
-rw------- 1 mirko users   242 Nov  2 22:21 bmapi.mk
-rw------- 1 mirko users  1351 Nov  2 22:21 bminfo.json
-rw------- 1 mirko users   130 Nov  2 22:21 buildroot.mk
-rw------- 1 mirko users   129 Nov  2 22:21 crosscompile.mk
-rwx------ 1 mirko users  3613 Nov  2 22:21 deploy_jupyter_board.py
-rw------- 1 mirko users   495 Nov  2 22:21 local.mk
-rw------- 1 mirko users   145 Nov  2 22:21 neuralbondconfig.json
drwx------ 2 mirko users    20 Nov  2 22:21 neurons
-rw------- 1 mirko users   145 Nov  2 22:21 simbatch.mk
-rwx------ 1 mirko users  4059 Nov  2 22:21 simbatch.py
-rw------- 1 mirko users 24057 Nov  2 22:21 simbatch_input.csv
-rw------- 1 mirko users  1100 Nov  2 22:21 sumapp.go
-rw------- 1 mirko users 21319 Nov  2 22:21 zedboard.xdc
-rw------- 1 mirko users    53 Nov  2 22:21 zedboard_maps.json
```

DEMO - BondMachine creation

```
_inputs 4 --n_outputs 3 --source_neuralbond banknote.json
[ Command >
cd proj_mlinfn
ls -al
[ Output  >
total 10
drwx------ 3 mirko users    20 Nov  2 22:21 .
drwx------ 3 mirko users    17 Nov  2 22:21 ..
-rw------- 1 mirko users 44179 Nov  2 22:21 Makefile
-rw------- 1 mirko users   397 Nov  2 22:21 authorized_keys
-rw------- 1 mirko users  1962 Nov  2 22:21 banknote.json
-rw------- 1 mirko users   150 Nov  2 22:21 bmapi.json
-rw------- 1 mirko users   242 Nov  2 22:21 bmapi.mk
-rw------- 1 mirko users  1351 Nov  2 22:21 bminfo.json
-rw------- 1 mirko users   130 Nov  2 22:21 buildroot.mk
-rw------- 1 mirko users   129 Nov  2 22:21 crosscompile.mk
-rwx------ 1 mirko users  3613 Nov  2 22:21 deploy_jupyter_board.py
-rw------- 1 mirko users   495 Nov  2 22:21 local.mk
-rw------- 1 mirko users   145 Nov  2 22:21 neuralbondconfig.json
drwx------ 2 mirko users    20 Nov  2 22:21 neurons
-rw------- 1 mirko users   145 Nov  2 22:21 simbatch.mk
-rwx------ 1 mirko users  4059 Nov  2 22:21 simbatch.py
-rw------- 1 mirko users 24057 Nov  2 22:21 simbatch_input.csv
-rw------- 1 mirko users  1100 Nov  2 22:21 sumapp.go
-rw------- 1 mirko users 21319 Nov  2 22:21 zedboard.xdc
-rw------- 1 mirko users    53 Nov  2 22:21 zedboard_maps.json
[ Command > cat local.mk
```

DEMO - BondMachine creation

```
-rw------- 1 mirko users   145 Nov  2 22:21 simbatch.mk
-rwx------ 1 mirko users  4059 Nov  2 22:21 simbatch.py
-rw------- 1 mirko users 24057 Nov  2 22:21 simbatch_input.csv
-rw------- 1 mirko users  1100 Nov  2 22:21 sumapp.go
-rw------- 1 mirko users 21319 Nov  2 22:21 zedboard.xdc
-rw------- 1 mirko users    53 Nov  2 22:21 zedboard_maps.json
[ Command > cat local.mk
[ Output  >
WORKING_DIR=working_dir
CURRENT_DIR=$(shell pwd)
SOURCE_NEURALBOND=banknote.json
NEURALBOND_LIBRARY=neurons
NEURALBOND_ARGS=-config-file neuralbondconfig.json -operating-mode fragment
BMINFO=bminfo.json
BOARD=zedboard
MAPFILE=zedboard_maps.json
SHOWARGS=-dot-detail 5
SHOWRENDERER=dot
VERILOG_OPTIONS=-comment-verilog
#BASM_ARGS=-d
BENCHCORE=i0,p0o0
#HDL_REGRESSION=bondmachine.sv
#BM_REGRESSION=bondmachine.json
include bmapi.mk
include crosscompile.mk
include buildroot.mk
include simbatch.mk
```

DEMO - BondMachine creation

```
-rwx------ 1 mirko users  4059 Nov  2 22:21 simbatch.py
-rw------- 1 mirko users 24057 Nov  2 22:21 simbatch_input.csv
-rw------- 1 mirko users  1100 Nov  2 22:21 sumapp.go
-rw------- 1 mirko users 21319 Nov  2 22:21 zedboard.xdc
-rw------- 1 mirko users    53 Nov  2 22:21 zedboard_maps.json
[ Command > cat local.mk
[ Output  >
WORKING_DIR=working_dir
CURRENT_DIR=$(shell pwd)
SOURCE_NEURALBOND=banknote.json
NEURALBOND_LIBRARY=neurons
NEURALBOND_ARGS=-config-file neuralbondconfig.json -operating-mode fragment
BMINFO=bminfo.json
BOARD=zedboard
MAPFILE=zedboard_maps.json
SHOWARGS=-dot-detail 5
SHOWRENDERER=dot
VERILOG_OPTIONS=-comment-verilog
#BASM_ARGS=-d
BENCHCORE=i0,p0o0
#HDL_REGRESSION=bondmachine.sv
#BM_REGRESSION=bondmachine.json
include bmapi.mk
include crosscompile.mk
include buildroot.mk
include simbatch.mk
[ Command > ls neurons
```

DEMO - BondMachine creation

```
[ Command > cat local.mk
[ Output  >
WORKING_DIR=working_dir
CURRENT_DIR=$(shell pwd)
SOURCE_NEURALBOND=banknote.json
NEURALBOND_LIBRARY=neurons
NEURALBOND_ARGS=-config-file neuralbondconfig.json -operating-mode fragment
BMINFO=bminfo.json
BOARD=zedboard
MAPFILE=zedboard_maps.json
SHOWARGS=-dot-detail 5
SHOWRENDERER=dot
VERILOG_OPTIONS=-comment-verilog
#BASM_ARGS=-d
BENCHCORE=i0,p0o0
#HDL_REGRESSION=bondmachine.sv
#BM_REGRESSION=bondmachine.json
include bmapi.mk
include crosscompile.mk
include buildroot.mk
include simbatch.mk
[ Command > ls neurons
[ Output  >
frag-linear.basm     frag-terminal.basm  rom-linear.basm     rom-terminal.basm  terminal.nb
frag-relu.basm       frag-weight.basm    rom-relu.basm       rom-weight.basm    weight.nb
frag-softmax.basm    linear.nb           rom-softmax.basm    softmax.nb
frag-summation.basm  relu.nb             rom-summation.basm  summation.nb
```

DEMO - BondMachine creation

```
[ Output  >
WORKING_DIR=working_dir
CURRENT_DIR=$(shell pwd)
SOURCE_NEURALBOND=banknote.json
NEURALBOND_LIBRARY=neurons
NEURALBOND_ARGS=-config-file neuralbondconfig.json -operating-mode fragment
BMINFO=bminfo.json
BOARD=zedboard
MAPFILE=zedboard_maps.json
SHOWARGS=-dot-detail 5
SHOWRENDERER=dot
VERILOG_OPTIONS=-comment-verilog
#BASM_ARGS=-d
BENCHCORE=i0,p0o0
#HDL_REGRESSION=bondmachine.sv
#BM_REGRESSION=bondmachine.json
include bmapi.mk
include crosscompile.mk
include buildroot.mk
include simbatch.mk
[ Command > ls neurons
[ Output  >
frag-linear.basm     frag-terminal.basm  rom-linear.basm     rom-terminal.basm  terminal.nb
frag-relu.basm       frag-weight.basm    rom-relu.basm       rom-weight.basm    weight.nb
frag-softmax.basm    linear.nb           rom-softmax.basm    softmax.nb
frag-summation.basm  relu.nb             rom-summation.basm  summation.nb
[ Command > cat neurons/frag-softmax.basm | head -n 15
```

DEMO - BondMachine creation

```
include crosscompile.mk
include buildroot.mk
include simbatch.mk
[ Command > ls neurons
[ Output  >
frag-linear.basm     frag-terminal.basm  rom-linear.basm     rom-terminal.basm  terminal.nb
frag-relu.basm       frag-weight.basm    rom-relu.basm       rom-weight.basm    weight.nb
frag-softmax.basm    linear.nb           rom-softmax.basm    softmax.nb
frag-summation.basm  relu.nb             rom-summation.basm  summation.nb
[ Command > cat neurons/frag-softmax.basm | head -n 15
[ Output  >
%fragment softmax iomode:sync template:true resout:r9
%meta literal resin {{ with $last := adds "10" .Params.inputs }}{{range $y := intRange "10" $last }}
{{printf "r%d:" $y}}{{end}}{{end}}
        mov     r8, 0f0.0
{{ with $last := adds "10" .Params.inputs }}
{{range $y := intRange "10" $last}}
{{printf "mov r1,r%d\n" $y}}
        mov     r0, 0f1.0
        mov     r2, 0f1.0
        mov     r3, 0f1.0
        mov     r4, 0f1.0
        mov     r5, 0f1.0
        mov     r7, {{$.Params.expprec}}
loop{{printf "%d" $y}}:
        multf   r2, r1
        multf   r3, r4
```

DEMO - BondMachine creation

```
include buildroot.mk
include simbatch.mk
[ Command > ls neurons
[ Output  >
frag-linear.basm     frag-terminal.basm  rom-linear.basm     rom-terminal.basm  terminal.nb
frag-relu.basm       frag-weight.basm    rom-relu.basm       rom-weight.basm    weight.nb
frag-softmax.basm    linear.nb           rom-softmax.basm    softmax.nb
frag-summation.basm  relu.nb             rom-summation.basm  summation.nb
[ Command > cat neurons/frag-softmax.basm | head -n 15
[ Output  >
%fragment softmax iomode:sync template:true resout:r9
%meta literal resin {{ with $last := adds "10" .Params.inputs }}{{range $y := intRange "10" $last }}
{{printf "r%d:" $y}}{{end}}{{end}}
        mov     r8, 0f0.0
{{ with $last := adds "10" .Params.inputs }}
{{range $y := intRange "10" $last}}
{{printf "mov r1,r%d\n" $y}}
        mov     r0, 0f1.0
        mov     r2, 0f1.0
        mov     r3, 0f1.0
        mov     r4, 0f1.0
        mov     r5, 0f1.0
        mov     r7, {{$.Params.expprec}}
loop{{printf "%d" $y}}:
        multf   r2, r1
        multf   r3, r4
[ Command > cp /tmp/modelBM.json banknote.json
```

DEMO - BondMachine creation

```
include buildroot.mk
include simbatch.mk
[ Command > ls neurons
[ Output  >
frag-linear.basm     frag-terminal.basm  rom-linear.basm     rom-terminal.basm  terminal.nb
frag-relu.basm       frag-weight.basm    rom-relu.basm       rom-weight.basm    weight.nb
frag-softmax.basm    linear.nb           rom-softmax.basm    softmax.nb
frag-summation.basm  relu.nb             rom-summation.basm  summation.nb
[ Command > cat neurons/frag-softmax.basm | head -n 15
[ Output  >
%fragment softmax iomode:sync template:true resout:r9
%meta literal resin {{ with $last := adds "10" .Params.inputs }}{{range $y := intRange "10" $last }}
{{printf "r%d:" $y}}{{end}}{{end}}
        mov     r8, 0f0.0
{{ with $last := adds "10" .Params.inputs }}
{{range $y := intRange "10" $last}}
{{printf "mov r1,r%d\n" $y}}
        mov     r0, 0f1.0
        mov     r2, 0f1.0
        mov     r3, 0f1.0
        mov     r4, 0f1.0
        mov     r5, 0f1.0
        mov     r7, {{$.Params.expprec}}
loop{{printf "%d" $y}}:
        multf   r2, r1
        multf   r3, r4
[ Command > cp /tmp/modelBM.json banknote.json
```

DEMO - BondMachine creation

```
include simbatch.mk
[ Command > ls neurons
[ Output  >
frag-linear.basm     frag-terminal.basm  rom-linear.basm     rom-terminal.basm  terminal.nb
frag-relu.basm       frag-weight.basm    rom-relu.basm       rom-weight.basm    weight.nb
frag-softmax.basm    linear.nb           rom-softmax.basm    softmax.nb
frag-summation.basm  relu.nb             rom-summation.basm  summation.nb
[ Command > cat neurons/frag-softmax.basm | head -n 15
[ Output  >
%fragment softmax iomode:sync template:true resout:r9
%meta literal resin {{ with $last := adds "10" .Params.inputs }}{{range $y := intRange "10" $last }}
{{printf "r%d:" $y}}{{end}}{{end}}
        mov     r8, 0f0.0
{{ with $last := adds "10" .Params.inputs }}
{{range $y := intRange "10" $last}}
{{printf "mov r1,r%d\n" $y}}
        mov     r0, 0f1.0
        mov     r2, 0f1.0
        mov     r3, 0f1.0
        mov     r4, 0f1.0
        mov     r5, 0f1.0
        mov     r7, {{$.Params.expprec}}
loop{{printf "%d" $y}}:
        multf   r2, r1
        multf   r3, r4
[ Command > cp /tmp/modelBM.json banknote.json
[ Command > make bondmachine
```

DEMO - BondMachine creation

```
%meta literal resin {{ with $last := adds "10" .Params.inputs }}{{range $y := intRange "10" $last }}
{{printf "r%d:" $y}}{{end}}{{end}}
        mov     r8, 0f0.0
{{ with $last := adds "10" .Params.inputs }}
{{range $y := intRange "10" $last}}
{{printf "mov r1,r%d\n" $y}}
        mov     r0, 0f1.0
        mov     r2, 0f1.0
        mov     r3, 0f1.0
        mov     r4, 0f1.0
        mov     r5, 0f1.0
        mov     r7, {{$.Params.expprec}}
loop{{printf "%d" $y}}:
        multf   r2, r1
        multf   r3, r4
[ Command > cp /tmp/modelBM.json banknote.json
[ Command > make bondmachine
[Project: proj_mlinfn] - [Working directory creation begin] - [Target: working_dir]
mkdir -p working_dir
[Project: proj_mlinfn] - [Working directory creation end]

[Project: proj_mlinfn] - [BondMachine generation begin] - [Target: working_dir/bondmachine_target]
neuralbond -net-file banknote.json -neuron-lib-path neurons -save-basm working_dir/bondmachine.basm
-config-file neuralbondconfig.json -operating-mode fragment -bminfo-file bminfo.json ; basm  -bminfo
-file bminfo.json -o working_dir/bondmachine.json working_dir/bondmachine.basm neurons/*.basm
[Project: proj_mlinfn] - [BondMachine generation end]
```

DEMO - BondMachine creation

```
{{printf "r%d:" $y}}{{end}}{{end}}
        mov     r8, 0f0.0
{{ with $last := adds "10" .Params.inputs }}
{{range $y := intRange "10" $last}}
{{printf "mov r1,r%d\n" $y}}
        mov     r0, 0f1.0
        mov     r2, 0f1.0
        mov     r3, 0f1.0
        mov     r4, 0f1.0
        mov     r5, 0f1.0
        mov     r7, {{$.Params.expprec}}
loop{{printf "%d" $y}}:
        multf   r2, r1
        multf   r3, r4
[ Command > cp /tmp/modelBM.json banknote.json
[ Command > make bondmachine
[Project: proj_mlinfn] - [Working directory creation begin] - [Target: working_dir]
mkdir -p working_dir
[Project: proj_mlinfn] - [Working directory creation end]

[Project: proj_mlinfn] - [BondMachine generation begin] - [Target: working_dir/bondmachine_target]
neuralbond -net-file banknote.json -neuron-lib-path neurons -save-basm working_dir/bondmachine.basm
-config-file neuralbondconfig.json -operating-mode fragment -bminfo-file bminfo.json ; basm  -bminfo
-file bminfo.json -o working_dir/bondmachine.json working_dir/bondmachine.basm neurons/*.basm
[Project: proj_mlinfn] - [BondMachine generation end]

[ Command > ls working_dir
```

DEMO - BondMachine creation

```
{{ with $last := adds "10" .Params.inputs }}
{{range $y := intRange "10" $last}}
{{printf "mov r1,r%d\n" $y}}
        mov     r0, 0f1.0
        mov     r2, 0f1.0
        mov     r3, 0f1.0
        mov     r4, 0f1.0
        mov     r5, 0f1.0
        mov     r7, {{$.Params.expprec}}
loop{{printf "%d" $y}}:
        multf   r2, r1
        multf   r3, r4
[ Command > cp /tmp/modelBM.json banknote.json
[ Command > make bondmachine
[Project: proj_mlinfn] - [Working directory creation begin] - [Target: working_dir]
mkdir -p working_dir
[Project: proj_mlinfn] - [Working directory creation end]

[Project: proj_mlinfn] - [BondMachine generation begin] - [Target: working_dir/bondmachine_target]
neuralbond -net-file banknote.json -neuron-lib-path neurons -save-basm working_dir/bondmachine.basm
-config-file neuralbondconfig.json -operating-mode fragment -bminfo-file bminfo.json ; basm  -bminfo
-file bminfo.json -o working_dir/bondmachine.json working_dir/bondmachine.basm neurons/*.basm
[Project: proj_mlinfn] - [BondMachine generation end]

[ Command > ls working_dir
[ Output  >
bondmachine.basm  bondmachine.json  bondmachine_target
```

DEMO - BondMachine creation

```
{{range $y := intRange "10" $last}}
{{printf "mov r1,r%d\n" $y}}
        mov     r0, 0f1.0
        mov     r2, 0f1.0
        mov     r3, 0f1.0
        mov     r4, 0f1.0
        mov     r5, 0f1.0
        mov     r7, {{$.Params.expprec}}
loop{{printf "%d" $y}}:
        multf   r2, r1
        multf   r3, r4
[ Command > cp /tmp/modelBM.json banknote.json
[ Command > make bondmachine
[Project: proj_mlinfn] - [Working directory creation begin] - [Target: working_dir]
mkdir -p working_dir
[Project: proj_mlinfn] - [Working directory creation end]

[Project: proj_mlinfn] - [BondMachine generation begin] - [Target: working_dir/bondmachine_target]
neuralbond -net-file banknote.json -neuron-lib-path neurons -save-basm working_dir/bondmachine.basm
-config-file neuralbondconfig.json -operating-mode fragment -bminfo-file bminfo.json ; basm  -bminfo
-file bminfo.json -o working_dir/bondmachine.json working_dir/bondmachine.basm neurons/*.basm
[Project: proj_mlinfn] - [BondMachine generation end]

[ Command > ls working_dir
[ Output  >
bondmachine.basm  bondmachine.json  bondmachine_target
[ Command > cat working_dir/bondmachine.basm
```

DEMO - BondMachine creation

```
%meta filinkatt downweightfi_3_1__4_1 fi:weightfi_3_1__4_1, type:input, index:0
%meta filinkatt downweightfi_3_1__4_1 fi:node_3_1, type:output, index:0
%meta filinkatt upweightfi_3_1__4_1 fi:node_4_1, type:input, index:0
%meta filinkatt upweightfi_3_1__4_1 fi:weightfi_3_1__4_1, type:output, index:0
%meta cpdef node_4_0 fragcollapse:node_4_0
%meta cpdef node_1_0 fragcollapse:node_1_0
%meta cpdef node_2_0 fragcollapse:node_2_0
%meta cpdef weightfi_0_3__1_0 fragcollapse:weightfi_0_3__1_0
%meta cpdef weightfi_2_0__3_0 fragcollapse:weightfi_2_0__3_0
%meta cpdef weightfi_0_0__1_0 fragcollapse:weightfi_0_0__1_0
%meta cpdef weightfi_2_1__3_0 fragcollapse:weightfi_2_1__3_0
%meta cpdef node_4_1 fragcollapse:node_4_1
%meta cpdef weightfi_2_1__3_1 fragcollapse:weightfi_2_1__3_1
%meta cpdef node_3_0 fragcollapse:node_3_0
%meta cpdef weightfi_3_0__4_0 fragcollapse:weightfi_3_0__4_0
%meta cpdef node_0_2 fragcollapse:node_0_2
%meta cpdef weightfi_0_2__1_0 fragcollapse:weightfi_0_2__1_0
%meta cpdef node_0_1 fragcollapse:node_0_1
%meta cpdef weightfi_1_0__2_0 fragcollapse:weightfi_1_0__2_0
%meta cpdef weightfi_1_0__2_1 fragcollapse:weightfi_1_0__2_1
%meta cpdef weightfi_2_0__3_1 fragcollapse:weightfi_2_0__3_1
%meta cpdef node_0_0 fragcollapse:node_0_0
%meta cpdef weightfi_0_1__1_0 fragcollapse:weightfi_0_1__1_0
%meta cpdef node_0_3 fragcollapse:node_0_3
%meta cpdef node_3_1 fragcollapse:node_3_1
%meta cpdef weightfi_3_1__4_1 fragcollapse:weightfi_3_1__4_1
%meta cpdef node_2_1 fragcollapse:node_2_1
```

DEMO - BondMachine creation

```
%meta filinkatt downweightfi_3_1__4_1 fi:node_3_1, type:output, index:0
%meta filinkatt upweightfi_3_1__4_1 fi:node_4_1, type:input, index:0
%meta filinkatt upweightfi_3_1__4_1 fi:weightfi_3_1__4_1, type:output, index:0
%meta cpdef node_4_0 fragcollapse:node_4_0
%meta cpdef node_1_0 fragcollapse:node_1_0
%meta cpdef node_2_0 fragcollapse:node_2_0
%meta cpdef weightfi_0_3__1_0 fragcollapse:weightfi_0_3__1_0
%meta cpdef weightfi_2_0__3_0 fragcollapse:weightfi_2_0__3_0
%meta cpdef weightfi_0_0__1_0 fragcollapse:weightfi_0_0__1_0
%meta cpdef weightfi_2_1__3_0 fragcollapse:weightfi_2_1__3_0
%meta cpdef node_4_1 fragcollapse:node_4_1
%meta cpdef weightfi_2_1__3_1 fragcollapse:weightfi_2_1__3_1
%meta cpdef node_3_0 fragcollapse:node_3_0
%meta cpdef weightfi_3_0__4_0 fragcollapse:weightfi_3_0__4_0
%meta cpdef node_0_2 fragcollapse:node_0_2
%meta cpdef weightfi_0_2__1_0 fragcollapse:weightfi_0_2__1_0
%meta cpdef node_0_1 fragcollapse:node_0_1
%meta cpdef weightfi_1_0__2_0 fragcollapse:weightfi_1_0__2_0
%meta cpdef weightfi_1_0__2_1 fragcollapse:weightfi_1_0__2_1
%meta cpdef weightfi_2_0__3_1 fragcollapse:weightfi_2_0__3_1
%meta cpdef node_0_0 fragcollapse:node_0_0
%meta cpdef weightfi_0_1__1_0 fragcollapse:weightfi_0_1__1_0
%meta cpdef node_0_3 fragcollapse:node_0_3
%meta cpdef node_3_1 fragcollapse:node_3_1
%meta cpdef weightfi_3_1__4_1 fragcollapse:weightfi_3_1__4_1
%meta cpdef node_2_1 fragcollapse:node_2_1
[ Command > make hdl
```

DEMO - BondMachine creation

```
%meta filinkatt downweightfi_3_1__4_1 fi:node_3_1, type:output, index:0
%meta filinkatt upweightfi_3_1__4_1 fi:node_4_1, type:input, index:0
%meta filinkatt upweightfi_3_1__4_1 fi:weightfi_3_1__4_1, type:output, index:0
%meta cpdef node_4_0 fragcollapse:node_4_0
%meta cpdef node_1_0 fragcollapse:node_1_0
%meta cpdef node_2_0 fragcollapse:node_2_0
%meta cpdef weightfi_0_3__1_0 fragcollapse:weightfi_0_3__1_0
%meta cpdef weightfi_2_0__3_0 fragcollapse:weightfi_2_0__3_0
%meta cpdef weightfi_0_0__1_0 fragcollapse:weightfi_0_0__1_0
%meta cpdef weightfi_2_1__3_0 fragcollapse:weightfi_2_1__3_0
%meta cpdef node_4_1 fragcollapse:node_4_1
%meta cpdef weightfi_2_1__3_1 fragcollapse:weightfi_2_1__3_1
%meta cpdef node_3_0 fragcollapse:node_3_0
%meta cpdef weightfi_3_0__4_0 fragcollapse:weightfi_3_0__4_0
%meta cpdef node_0_2 fragcollapse:node_0_2
%meta cpdef weightfi_0_2__1_0 fragcollapse:weightfi_0_2__1_0
%meta cpdef node_0_1 fragcollapse:node_0_1
%meta cpdef weightfi_1_0__2_0 fragcollapse:weightfi_1_0__2_0
%meta cpdef weightfi_1_0__2_1 fragcollapse:weightfi_1_0__2_1
%meta cpdef weightfi_2_0__3_1 fragcollapse:weightfi_2_0__3_1
%meta cpdef node_0_0 fragcollapse:node_0_0
%meta cpdef weightfi_0_1__1_0 fragcollapse:weightfi_0_1__1_0
%meta cpdef node_0_3 fragcollapse:node_0_3
%meta cpdef node_3_1 fragcollapse:node_3_1
%meta cpdef weightfi_3_1__4_1 fragcollapse:weightfi_3_1__4_1
%meta cpdef node_2_1 fragcollapse:node_2_1
[ Command > make hdl
```

DEMO - BondMachine creation

```
%meta filinkatt upweightfi_3_1__4_1 fi:node_4_1, type:input, index:0
%meta filinkatt upweightfi_3_1__4_1 fi:weightfi_3_1__4_1, type:output, index:0
%meta cpdef node_4_0 fragcollapse:node_4_0
%meta cpdef node_1_0 fragcollapse:node_1_0
%meta cpdef node_2_0 fragcollapse:node_2_0
%meta cpdef weightfi_0_3__1_0 fragcollapse:weightfi_0_3__1_0
%meta cpdef weightfi_2_0__3_0 fragcollapse:weightfi_2_0__3_0
%meta cpdef weightfi_0_0__1_0 fragcollapse:weightfi_0_0__1_0
%meta cpdef weightfi_2_1__3_0 fragcollapse:weightfi_2_1__3_0
%meta cpdef node_4_1 fragcollapse:node_4_1
%meta cpdef weightfi_2_1__3_1 fragcollapse:weightfi_2_1__3_1
%meta cpdef node_3_0 fragcollapse:node_3_0
%meta cpdef weightfi_3_0__4_0 fragcollapse:weightfi_3_0__4_0
%meta cpdef node_0_2 fragcollapse:node_0_2
%meta cpdef weightfi_0_2__1_0 fragcollapse:weightfi_0_2__1_0
%meta cpdef node_0_1 fragcollapse:node_0_1
%meta cpdef weightfi_1_0__2_0 fragcollapse:weightfi_1_0__2_0
%meta cpdef weightfi_1_0__2_1 fragcollapse:weightfi_1_0__2_1
%meta cpdef weightfi_2_0__3_1 fragcollapse:weightfi_2_0__3_1
%meta cpdef node_0_0 fragcollapse:node_0_0
%meta cpdef weightfi_0_1__1_0 fragcollapse:weightfi_0_1__1_0
%meta cpdef node_0_3 fragcollapse:node_0_3
%meta cpdef node_3_1 fragcollapse:node_3_1
%meta cpdef weightfi_3_1__4_1 fragcollapse:weightfi_3_1__4_1
%meta cpdef node_2_1 fragcollapse:node_2_1
[ Command > make hdl
[ Command > make show
```

DEMO - BondMachine creation

```
%meta cpdef weightfi_2_0__3_0 fragcollapse:weightfi_2_0__3_0
%meta cpdef weightfi_0_0__1_0 fragcollapse:weightfi_0_0__1_0
%meta cpdef weightfi_2_1__3_0 fragcollapse:weightfi_2_1__3_0
%meta cpdef node_4_1 fragcollapse:node_4_1
%meta cpdef weightfi_2_1__3_1 fragcollapse:weightfi_2_1__3_1
%meta cpdef node_3_0 fragcollapse:node_3_0
%meta cpdef weightfi_3_0__4_0 fragcollapse:weightfi_3_0__4_0
%meta cpdef node_0_2 fragcollapse:node_0_2
%meta cpdef weightfi_0_2__1_0 fragcollapse:weightfi_0_2__1_0
%meta cpdef node_0_1 fragcollapse:node_0_1
%meta cpdef weightfi_1_0__2_0 fragcollapse:weightfi_1_0__2_0
%meta cpdef weightfi_1_0__2_1 fragcollapse:weightfi_1_0__2_1
%meta cpdef weightfi_2_0__3_1 fragcollapse:weightfi_2_0__3_1
%meta cpdef node_0_0 fragcollapse:node_0_0
%meta cpdef weightfi_0_1__1_0 fragcollapse:weightfi_0_1__1_0
%meta cpdef node_0_3 fragcollapse:node_0_3
%meta cpdef node_3_1 fragcollapse:node_3_1
%meta cpdef weightfi_3_1__4_1 fragcollapse:weightfi_3_1__4_1
%meta cpdef node_2_1 fragcollapse:node_2_1
[ Command > make hdl
[ Command > make show
[ Output  >
[Project: proj_mlinfn] - [BondMachine diagram show begin] - [Target: show]
bondmachine -bondmachine-file working_dir/bondmachine.json -emit-dot -dot-detail 5 -bminfo-file bmin
fo.json | dot -Txlib
[Project: proj_mlinfn] - [BondMachine diagram show end]
```

BondMachine creation

The outcome of this second part of the demo are:

- bondmachine.json, a representation of the generated abstract machine
- Al the HDL files needed to build the firmware for the given board

Demo - BondMachine simulation

Demo - BondMachine simulation

Demo - BondMachine simulation

Demo - BondMachine simulation

```
[ Command > mkdir Example
[ Command > cd Example
[ Command > bmhelper create --project_name mlinfn --board zedboard --project_type neural_network --n
_inputs 4 --n_outputs 3 --source_neuralbond banknote.json
```

Demo - BondMachine simulation

```
[ Command > mkdir Example
[ Command > cd Example
[ Command > bmhelper create --project_name mlinfn --board zedboard --project_type neural_network --n
_inputs 4 --n_outputs 3 --source_neuralbond banknote.json
```

Demo - BondMachine simulation

```
[ Command > mkdir Example
[ Command > cd Example
[ Command > bmhelper create --project_name mlinfn --board zedboard --project_type neural_network --n
_inputs 4 --n_outputs 3 --source_neuralbond banknote.json
[ Command > cd proj_mlinfn
```

Demo - BondMachine simulation

```
[ Command > mkdir Example
[ Command > cd Example
[ Command > bmhelper create --project_name mlinfn --board zedboard --project_type neural_network --n
_inputs 4 --n_outputs 3 --source_neuralbond banknote.json
[ Command > cd proj_mlinfn
```

Demo - BondMachine simulation

```
[ Command > mkdir Example
[ Command > cd Example
[ Command > bmhelper create --project_name mlinfn --board zedboard --project_type neural_network --n
_inputs 4 --n_outputs 3 --source_neuralbond banknote.json
[ Command > cd proj_mlinfn
[ Command > cp /tmp/sim.csv .
```

Demo - BondMachine simulation

```
[ Command > mkdir Example
[ Command > cd Example
[ Command > bmhelper create --project_name mlinfn --board zedboard --project_type neural_network --n
_inputs 4 --n_outputs 3 --source_neuralbond banknote.json
[ Command > cd proj_mlinfn
[ Command > cp /tmp/sim.csv .
```

Demo - BondMachine simulation

```
[ Command > mkdir Example
[ Command > cd Example
[ Command > bmhelper create --project_name mlinfn --board zedboard --project_type neural_network --n
_inputs 4 --n_outputs 3 --source_neuralbond banknote.json
[ Command > cd proj_mlinfn
[ Command > cp /tmp/sim.csv .
[ Command > make simbatch
```

Demo - BondMachine simulation

```
1.316250120615847
Running simulation with inputs: 0f-1.0601420171169955,0f0.3471542056645857,0f-0.4248275125188447,0f-
0.04608508181009227
Running simulation with inputs: 0f-0.15228760297525445,0f-0.2821256600040472,0f-0.3931947744117846,0
f0.5712245546772439
Running simulation with inputs: 0f1.052405089774165,0f0.7521166535304541,0f-0.7981025904661143,0f0.3
9395848746270123
Running simulation with inputs: 0f-0.324656804509,0f-0.15459195394199834,0f-0.7235721768066175,0f0.2
947911065500622
Running simulation with inputs: 0f1.1202121241061977,0f-0.05885513674190243,0f-0.03632330979904628,0
f1.4916348403989907
Running simulation with inputs: 0f-1.5832950470099985,0f0.18817820405272936,0f-0.14704366178162517,0
f0.2538807872456312
Running simulation with inputs: 0f-0.2817404268789742,0f-1.2433487678699013,0f0.7539298193063557,0f1
.3088205957275203
Running simulation with inputs: 0f-0.9459019049271576,0f-0.32230699215865727,0f0.3011633249327807,0f
0.8005548150124344
Running simulation with inputs: 0f0.3527853059363061,0f-0.19267696420599642,0f-0.8155007117971548,0f
1.0596199512474536
Running simulation with inputs: 0f1.0634254876935534,0f-1.0567651440981527,0f0.4696066746895383,0f0.
6412610081648472
Running simulation with inputs: 0f-0.24940573706008093,0f1.0770592106221761,0f-1.0709577426405883,0f
-0.6442337339483407
Running simulation with inputs: 0f0.8249426728456427,0f1.5484150348383172,0f-1.1686087366365605,0f-1
.5435897047849427
[Project: proj_mlinfn] - [BondMachine simbatch end]
```

Demo - BondMachine simulation

```
Running simulation with inputs: 0f-1.0601420171169955,0f0.3471542056645857,0f-0.4248275125188447,0f-
0.04608508181009227
Running simulation with inputs: 0f-0.15228760297525445,0f-0.2821256600040472,0f-0.3931947744117846,0
f0.5712245546772439
Running simulation with inputs: 0f1.052405089774165,0f0.7521166535304541,0f-0.7981025904661143,0f0.3
9395848746270123
Running simulation with inputs: 0f-0.324656804509,0f-0.15459195394199834,0f-0.7235721768066175,0f0.2
947911065500622
Running simulation with inputs: 0f1.1202121241061977,0f-0.05885513674190243,0f-0.03632330979904628,0
f1.4916348403989907
Running simulation with inputs: 0f-1.5832950470099985,0f0.18817820405272936,0f-0.14704366178162517,0
f0.2538807872456312
Running simulation with inputs: 0f-0.2817404268789742,0f-1.2433487678699013,0f0.7539298193063557,0f1
.3088205957275203
Running simulation with inputs: 0f-0.9459019049271576,0f-0.32230699215865727,0f0.3011633249327807,0f
0.8005548150124344
Running simulation with inputs: 0f0.3527853059363061,0f-0.19267696420599642,0f-0.8155007117971548,0f
1.0596199512474536
Running simulation with inputs: 0f1.0634254876935534,0f-1.0567651440981527,0f0.4696066746895383,0f0.
6412610081648472
Running simulation with inputs: 0f-0.24940573706008093,0f1.0770592106221761,0f-1.0709577426405883,0f
-0.6442337339483407
Running simulation with inputs: 0f0.8249426728456427,0f1.5484150348383172,0f-1.1686087366365605,0f-1
.5435897047849427
[Project: proj_mlinfn] - [BondMachine simbatch end]

[ Command > cat working_dir/simbatch_output.csv
```

Demo - BondMachine simulation

```
0.71279794,0.28720203,0
0.6313562,0.36864382,0
0.7589688,0.24103124,0
0.6479448,0.35205516,0
0.3601988,0.63980114,1
0.6425791,0.35742098,0
0.5682741,0.43172595,0
0.61973804,0.38026193,0
0.6914931,0.3085069,0
0.6783158,0.32168424,0
0.4921839,0.5078161,1
0.37793863,0.6220614,1
0.66365564,0.33634433,0
0.6749563,0.32504368,0
0.66059536,0.3394046,0
0.4266389,0.57336116,1
0.4380828,0.56191725,1
0.6834962,0.31650382,0
0.4042624,0.59573764,1
0.63697994,0.3630201,0
0.36208335,0.6379167,1
0.403224,0.59677607,1
0.40639094,0.5936091,1
0.4439535,0.5560465,1
0.593614,0.40638596,0
0.5749001,0.42509994,0
0.77141094,0.22858903,0
```

Simulation

The outcome of this third part of the demo is:

- simbatchoutput.csv, a simulated CSV files containing the output probabilities and the prediction

DEMO - BondMachine accelerator creation

DEMO - BondMachine accelerator creation

DEMO - BondMachine accelerator creation

DEMO - BondMachine accelerator creation

```
[ Command > mkdir Example
[ Command > cd Example
[ Command > bmhelper create --project_name mlinfn --board zedboard --project_type neural_network --n
_inputs 4 --n_outputs 3 --source_neuralbond banknote.json
```

DEMO - BondMachine accelerator creation

```
[ Command > mkdir Example
[ Command > cd Example
[ Command > bmhelper create --project_name mlinfn --board zedboard --project_type neural_network --n
_inputs 4 --n_outputs 3 --source_neuralbond banknote.json
```

DEMO - BondMachine accelerator creation

```
[ Command > mkdir Example
[ Command > cd Example
[ Command > bmhelper create --project_name mlinfn --board zedboard --project_type neural_network --n
_inputs 4 --n_outputs 3 --source_neuralbond banknote.json
[ Command > cd proj_mlinfn
cat local.mk
```

DEMO - BondMachine accelerator creation

```
[ Command > mkdir Example
[ Command > cd Example
[ Command > bmhelper create --project_name mlinfn --board zedboard --project_type neural_network --n
_inputs 4 --n_outputs 3 --source_neuralbond banknote.json
[ Command > cd proj_mlinfn
cat local.mk
[ Output  >
WORKING_DIR=working_dir
CURRENT_DIR=$(shell pwd)
SOURCE_NEURALBOND=banknote.json
NEURALBOND_LIBRARY=neurons
NEURALBOND_ARGS=-config-file neuralbondconfig.json -operating-mode fragment
BMINFO=bminfo.json
BOARD=zedboard
MAPFILE=zedboard_maps.json
SHOWARGS=-dot-detail 5
SHOWRENDERER=dot
VERILOG_OPTIONS=-comment-verilog
#BASM_ARGS=-d
BENCHCORE=i0,p0o0
#HDL_REGRESSION=bondmachine.sv
#BM_REGRESSION=bondmachine.json
include bmapi.mk
include crosscompile.mk
include buildroot.mk
include simbatch.mk
```

DEMO - BondMachine accelerator creation

```
[ Command > mkdir Example
[ Command > cd Example
[ Command > bmhelper create --project_name mlinfn --board zedboard --project_type neural_network --n
_inputs 4 --n_outputs 3 --source_neuralbond banknote.json
[ Command > cd proj_mlinfn
cat local.mk
[ Output  >
WORKING_DIR=working_dir
CURRENT_DIR=$(shell pwd)
SOURCE_NEURALBOND=banknote.json
NEURALBOND_LIBRARY=neurons
NEURALBOND_ARGS=-config-file neuralbondconfig.json -operating-mode fragment
BMINFO=bminfo.json
BOARD=zedboard
MAPFILE=zedboard_maps.json
SHOWARGS=-dot-detail 5
SHOWRENDERER=dot
VERILOG_OPTIONS=-comment-verilog
#BASM_ARGS=-d
BENCHCORE=i0,p0o0
#HDL_REGRESSION=bondmachine.sv
#BM_REGRESSION=bondmachine.json
include bmapi.mk
include crosscompile.mk
include buildroot.mk
include simbatch.mk
[ Command > make accelerator
```

DEMO - BondMachine accelerator creation

```
INFO: [IP_Flow 19-3166] Bus Interface 'S00_AXI': References existing memory map 'S00_AXI'.
# set_property core_revision 4 [ipx::current_core]
# ipx::update_source_project_archive -component [ipx::current_core]
# ipx::create_xgui_files [ipx::current_core]
# ipx::update_checksums [ipx::current_core]
# ipx::save_core [ipx::current_core]
# ipx::move_temp_component_back -component [ipx::current_core]
# close_project -delete
# update_ip_catalog -rebuild -repo_path ${ip_directory}
INFO: [IP_Flow 19-725] Reloaded user IP repository 'ip_repo'
# close_project -delete
# exit
INFO: [Common 17-206] Exiting Vivado at Wed Nov  2 23:03:37 2022...
cp -a working_dir/bondmachine.sv working_dir/ip_repo/bondmachineip_1.0/hdl/bondmachine.sv
# Comments
bash -c "cd working_dir ; ./vivadoAXIcomment.sh"
# Insert the AXI code
bash -c "cd working_dir ; sed -i -e '/Add user logic here/r aux/axipatch.txt' ./ip_repo/bondmachinei
p_1.0/hdl/bondmachineip_v1_0_S00_AXI.v"
bash -c "cd working_dir ; sed -i -e '/Users to add ports here/r aux/designexternal.txt' ./ip_repo/bo
ndmachineip_1.0/hdl/bondmachineip_v1_0_S00_AXI.v"
bash -c "cd working_dir ; sed -i -e '/Users to add ports here/r aux/designexternal.txt' ./ip_repo/bo
ndmachineip_1.0/hdl/bondmachineip_v1_0.v"
bash -c "cd working_dir ; sed -i -e '/bondmachineip_v1_0_S00_AXI_inst/r aux/designexternalinst.txt'
./ip_repo/bondmachineip_1.0/hdl/bondmachineip_v1_0.v"
[Project: proj_mlinfn] - [Vivado toolchain - IP accelerator creation end]
```

DEMO - BondMachine accelerator creation

```
# set_property core_revision 4 [ipx::current_core]
# ipx::update_source_project_archive -component [ipx::current_core]
# ipx::create_xgui_files [ipx::current_core]
# ipx::update_checksums [ipx::current_core]
# ipx::save_core [ipx::current_core]
# ipx::move_temp_component_back -component [ipx::current_core]
# close_project -delete
# update_ip_catalog -rebuild -repo_path ${ip_directory}
INFO: [IP_Flow 19-725] Reloaded user IP repository 'ip_repo'
# close_project -delete
# exit
INFO: [Common 17-206] Exiting Vivado at Wed Nov  2 23:03:37 2022...
cp -a working_dir/bondmachine.sv working_dir/ip_repo/bondmachineip_1.0/hdl/bondmachine.sv
# Comments
bash -c "cd working_dir ; ./vivadoAXIcomment.sh"
# Insert the AXI code
bash -c "cd working_dir ; sed -i -e '/Add user logic here/r aux/axipatch.txt' ./ip_repo/bondmachinei
p_1.0/hdl/bondmachineip_v1_0_S00_AXI.v"
bash -c "cd working_dir ; sed -i -e '/Users to add ports here/r aux/designexternal.txt' ./ip_repo/bo
ndmachineip_1.0/hdl/bondmachineip_v1_0_S00_AXI.v"
bash -c "cd working_dir ; sed -i -e '/Users to add ports here/r aux/designexternal.txt' ./ip_repo/bo
ndmachineip_1.0/hdl/bondmachineip_v1_0.v"
bash -c "cd working_dir ; sed -i -e '/bondmachineip_v1_0_S00_AXI_inst/r aux/designexternalinst.txt'
./ip_repo/bondmachineip_1.0/hdl/bondmachineip_v1_0.v"
[Project: proj_mlinfn] - [Vivado toolchain - IP accelerator creation end]

[ Command > make design
```

DEMO - BondMachine accelerator creation

```
# make_wrapper -files [get_files ${project_dir}/${project_name}.srcs/sources_1/bd/bm_design/bm_desig
n.bd] -top
INFO: [BD 41-1662] The design 'bm_design.bd' is already validated. Therefore parameter propagation w
ill not be re-run.
Wrote  : </tmp/tmpof_4uxc5/Example/proj_mlinfn/working_dir/bmaccelerator/bmaccelerator.srcs/sources_
1/bd/bm_design/bm_design.bd>
VHDL Output written to : /tmp/tmpof_4uxc5/Example/proj_mlinfn/working_dir/bmaccelerator/bmaccelerato
r.srcs/sources_1/bd/bm_design/synth/bm_design.v
VHDL Output written to : /tmp/tmpof_4uxc5/Example/proj_mlinfn/working_dir/bmaccelerator/bmaccelerato
r.srcs/sources_1/bd/bm_design/sim/bm_design.v
VHDL Output written to : /tmp/tmpof_4uxc5/Example/proj_mlinfn/working_dir/bmaccelerator/bmaccelerato
r.srcs/sources_1/bd/bm_design/hdl/bm_design_wrapper.v
# update_compile_order -fileset sources_1
CRITICAL WARNING: [filemgmt 20-730] Could not find a top module in the fileset sources_1.
Resolution: With the gui up, review the source files in the Sources window. Use Add Sources to add a
ny needed sources. If the files are disabled, enable them. You can also select the file and choose S
et Used In from the pop-up menu. Review if they are being used at the proper points of the flow.
# add_files -norecurse -scan_for_includes ${project_dir}/${project_name}.srcs/sources_1/bd/bm_design
/hdl/bm_design_wrapper.v
# update_compile_order -fileset sources_1
# add_files -fileset constrs_1 -norecurse zedboard.xdc
# update_compile_order -fileset sources_1
# close_project
# exit
INFO: [Common 17-206] Exiting Vivado at Wed Nov  2 23:04:33 2022...
[Project: proj_mlinfn] - [Vivado toolchain - design creation end]
```

DEMO - BondMachine accelerator creation

```
n.bd] -top
INFO: [BD 41-1662] The design 'bm_design.bd' is already validated. Therefore parameter propagation w
ill not be re-run.
Wrote  : </tmp/tmpof_4uxc5/Example/proj_mlinfn/working_dir/bmaccelerator/bmaccelerator.srcs/sources_
1/bd/bm_design/bm_design.bd>
VHDL Output written to : /tmp/tmpof_4uxc5/Example/proj_mlinfn/working_dir/bmaccelerator/bmaccelerato
r.srcs/sources_1/bd/bm_design/synth/bm_design.v
VHDL Output written to : /tmp/tmpof_4uxc5/Example/proj_mlinfn/working_dir/bmaccelerator/bmaccelerato
r.srcs/sources_1/bd/bm_design/sim/bm_design.v
VHDL Output written to : /tmp/tmpof_4uxc5/Example/proj_mlinfn/working_dir/bmaccelerator/bmaccelerato
r.srcs/sources_1/bd/bm_design/hdl/bm_design_wrapper.v
# update_compile_order -fileset sources_1
CRITICAL WARNING: [filemgmt 20-730] Could not find a top module in the fileset sources_1.
Resolution: With the gui up, review the source files in the Sources window. Use Add Sources to add a
ny needed sources. If the files are disabled, enable them. You can also select the file and choose S
et Used In from the pop-up menu. Review if they are being used at the proper points of the flow.
# add_files -norecurse -scan_for_includes ${project_dir}/${project_name}.srcs/sources_1/bd/bm_design
/hdl/bm_design_wrapper.v
# update_compile_order -fileset sources_1
# add_files -fileset constrs_1 -norecurse zedboard.xdc
# update_compile_order -fileset sources_1
# close_project
# exit
INFO: [Common 17-206] Exiting Vivado at Wed Nov  2 23:04:33 2022...
[Project: proj_mlinfn] - [Vivado toolchain - design creation end]

[ Command > make design_synthesis
```

DEMO - BondMachine accelerator creation

```
INFO: [Project 1-571] Translating synthesized netlist
Netlist sorting complete. Time (s): cpu = 00:00:00.01 ; elapsed = 00:00:00.01 . Memory (MB): peak =
2133.133 ; gain = 0.000 ; free physical = 3826 ; free virtual = 4432
INFO: [Project 1-570] Preparing netlist for logic optimization
INFO: [Opt 31-138] Pushed 0 inverter(s) to 0 load pin(s).
Netlist sorting complete. Time (s): cpu = 00:00:00 ; elapsed = 00:00:00 . Memory (MB): peak = 2140.0
62 ; gain = 0.000 ; free physical = 3774 ; free virtual = 4381
INFO: [Project 1-111] Unisim Transformation Summary:
No Unisim elements were transformed.

INFO: [Common 17-83] Releasing license: Synthesis
36 Infos, 26 Warnings, 0 Critical Warnings and 0 Errors encountered.
synth_design completed successfully
synth_design: Time (s): cpu = 00:00:49 ; elapsed = 00:00:51 . Memory (MB): peak = 2140.062 ; gain =
55.961 ; free physical = 3905 ; free virtual = 4512
INFO: [Common 17-1381] The checkpoint '/tmp/tmpof_4uxc5/Example/proj_mlinfn/working_dir/bmaccelerato
r/bmaccelerator.runs/synth_1/bm_design_wrapper.dcp' has been generated.
INFO: [runtcl-4] Executing : report_utilization -file bm_design_wrapper_utilization_synth.rpt -pb bm
_design_wrapper_utilization_synth.pb
INFO: [Common 17-206] Exiting Vivado at Wed Nov  2 23:17:23 2022...
[Wed Nov  2 23:17:33 2022] synth_1 finished
wait_on_run: Time (s): cpu = 00:15:18 ; elapsed = 00:12:01 . Memory (MB): peak = 2258.160 ; gain = 0
.000 ; free physical = 4618 ; free virtual = 5223
# exit
INFO: [Common 17-206] Exiting Vivado at Wed Nov  2 23:17:34 2022...
[Project: proj_mlinfn] - [Vivado toolchain - design synthesis end]
```

DEMO - BondMachine accelerator creation

```
Netlist sorting complete. Time (s): cpu = 00:00:00.01 ; elapsed = 00:00:00.01 . Memory (MB): peak =
2133.133 ; gain = 0.000 ; free physical = 3826 ; free virtual = 4432
INFO: [Project 1-570] Preparing netlist for logic optimization
INFO: [Opt 31-138] Pushed 0 inverter(s) to 0 load pin(s).
Netlist sorting complete. Time (s): cpu = 00:00:00 ; elapsed = 00:00:00 . Memory (MB): peak = 2140.0
62 ; gain = 0.000 ; free physical = 3774 ; free virtual = 4381
INFO: [Project 1-111] Unisim Transformation Summary:
No Unisim elements were transformed.

INFO: [Common 17-83] Releasing license: Synthesis
36 Infos, 26 Warnings, 0 Critical Warnings and 0 Errors encountered.
synth_design completed successfully
synth_design: Time (s): cpu = 00:00:49 ; elapsed = 00:00:51 . Memory (MB): peak = 2140.062 ; gain =
55.961 ; free physical = 3905 ; free virtual = 4512
INFO: [Common 17-1381] The checkpoint '/tmp/tmpof_4uxc5/Example/proj_mlinfn/working_dir/bmaccelerato
r/bmaccelerator.runs/synth_1/bm_design_wrapper.dcp' has been generated.
INFO: [runtcl-4] Executing : report_utilization -file bm_design_wrapper_utilization_synth.rpt -pb bm
_design_wrapper_utilization_synth.pb
INFO: [Common 17-206] Exiting Vivado at Wed Nov  2 23:17:23 2022...
[Wed Nov  2 23:17:33 2022] synth_1 finished
wait_on_run: Time (s): cpu = 00:15:18 ; elapsed = 00:12:01 . Memory (MB): peak = 2258.160 ; gain = 0
.000 ; free physical = 4618 ; free virtual = 5223
# exit
INFO: [Common 17-206] Exiting Vivado at Wed Nov  2 23:17:34 2022...
[Project: proj_mlinfn] - [Vivado toolchain - design synthesis end]

[ Command > make design_implementation
```

DEMO - BondMachine accelerator creation

```
report_power completed successfully
report_power: Time (s): cpu = 00:00:27 ; elapsed = 00:00:15 . Memory (MB): peak = 3082.508 ; gain =
26.992 ; free physical = 3048 ; free virtual = 3694
INFO: [runtcl-4] Executing : report_route_status -file bm_design_wrapper_route_status.rpt -pb bm_des
ign_wrapper_route_status.pb
INFO: [runtcl-4] Executing : report_timing_summary -max_paths 10 -file bm_design_wrapper_timing_summ
ary_routed.rpt -pb bm_design_wrapper_timing_summary_routed.pb -rpx bm_design_wrapper_timing_summary_
routed.rpx -warn_on_violation
INFO: [Timing 38-91] UpdateTimingParams: Speed grade: -1, Delay Type: min_max.
INFO: [Timing 38-191] Multithreading enabled for timing update using a maximum of 4 CPUs
INFO: [runtcl-4] Executing : report_incremental_reuse -file bm_design_wrapper_incremental_reuse_rout
ed.rpt
INFO: [Vivado_Tcl 4-1062] Incremental flow is disabled. No incremental reuse Info to report.
INFO: [runtcl-4] Executing : report_clock_utilization -file bm_design_wrapper_clock_utilization_rout
ed.rpt
INFO: [runtcl-4] Executing : report_bus_skew -warn_on_violation -file bm_design_wrapper_bus_skew_rou
ted.rpt -pb bm_design_wrapper_bus_skew_routed.pb -rpx bm_design_wrapper_bus_skew_routed.rpx
INFO: [Timing 38-91] UpdateTimingParams: Speed grade: -1, Delay Type: min_max.
INFO: [Timing 38-191] Multithreading enabled for timing update using a maximum of 4 CPUs
INFO: [Common 17-206] Exiting Vivado at Wed Nov  2 23:23:42 2022...
[Wed Nov  2 23:23:58 2022] impl_1 finished
wait_on_run: Time (s): cpu = 00:00:02 ; elapsed = 00:05:46 . Memory (MB): peak = 2202.250 ; gain = 0
.000 ; free physical = 4625 ; free virtual = 5273
# exit
INFO: [Common 17-206] Exiting Vivado at Wed Nov  2 23:23:58 2022...
[Project: proj_mlinfn] - [Vivado toolchain - design implementation end]
```

DEMO - BondMachine accelerator creation

```
report_power: Time (s): cpu = 00:00:27 ; elapsed = 00:00:15 . Memory (MB): peak = 3082.508 ; gain =
26.992 ; free physical = 3048 ; free virtual = 3694
INFO: [runtcl-4] Executing : report_route_status -file bm_design_wrapper_route_status.rpt -pb bm_des
ign_wrapper_route_status.pb
INFO: [runtcl-4] Executing : report_timing_summary -max_paths 10 -file bm_design_wrapper_timing_summ
ary_routed.rpt -pb bm_design_wrapper_timing_summary_routed.pb -rpx bm_design_wrapper_timing_summary_
routed.rpx -warn_on_violation
INFO: [Timing 38-91] UpdateTimingParams: Speed grade: -1, Delay Type: min_max.
INFO: [Timing 38-191] Multithreading enabled for timing update using a maximum of 4 CPUs
INFO: [runtcl-4] Executing : report_incremental_reuse -file bm_design_wrapper_incremental_reuse_rout
ed.rpt
INFO: [Vivado_Tcl 4-1062] Incremental flow is disabled. No incremental reuse Info to report.
INFO: [runtcl-4] Executing : report_clock_utilization -file bm_design_wrapper_clock_utilization_rout
ed.rpt
INFO: [runtcl-4] Executing : report_bus_skew -warn_on_violation -file bm_design_wrapper_bus_skew_rou
ted.rpt -pb bm_design_wrapper_bus_skew_routed.pb -rpx bm_design_wrapper_bus_skew_routed.rpx
INFO: [Timing 38-91] UpdateTimingParams: Speed grade: -1, Delay Type: min_max.
INFO: [Timing 38-191] Multithreading enabled for timing update using a maximum of 4 CPUs
INFO: [Common 17-206] Exiting Vivado at Wed Nov  2 23:23:42 2022...
[Wed Nov  2 23:23:58 2022] impl_1 finished
wait_on_run: Time (s): cpu = 00:00:02 ; elapsed = 00:05:46 . Memory (MB): peak = 2202.250 ; gain = 0
.000 ; free physical = 4625 ; free virtual = 5273
# exit
INFO: [Common 17-206] Exiting Vivado at Wed Nov  2 23:23:58 2022...
[Project: proj_mlinfn] - [Vivado toolchain - design implementation end]

[ Command > make design_bitstream
```

DEMO - BondMachine accelerator creation

```
the MREG and PREG registers to be used.  If the DSP48 was instantiated in the design, it is suggeste
d to set both the MREG and PREG attributes to 1 when performing multiply functions.
INFO: [Vivado 12-3199] DRC finished with 0 Errors, 84 Warnings
INFO: [Vivado 12-3200] Please refer to the DRC report (report_drc) for more information.
INFO: [Designutils 20-2272] Running write_bitstream with 4 threads.
Loading data files...
Loading site data...
Loading route data...
Processing options...
Creating bitmap...
Creating bitstream...
Writing bitstream ./bm_design_wrapper.bit...
Writing bitstream ./bm_design_wrapper.bin...
INFO: [Vivado 12-1842] Bitgen Completed Successfully.
INFO: [Common 17-83] Releasing license: Implementation
22 Infos, 84 Warnings, 0 Critical Warnings and 0 Errors encountered.
write_bitstream completed successfully
write_bitstream: Time (s): cpu = 00:00:58 ; elapsed = 00:00:44 . Memory (MB): peak = 2909.914 ; gain
 = 498.211 ; free physical = 3484 ; free virtual = 4141
INFO: [Common 17-206] Exiting Vivado at Wed Nov  2 23:26:13 2022...
[Wed Nov  2 23:26:14 2022] impl_1 finished
wait_on_run: Time (s): cpu = 00:01:47 ; elapsed = 00:01:38 . Memory (MB): peak = 2186.242 ; gain = 0
.000 ; free physical = 4694 ; free virtual = 5344
# exit
INFO: [Common 17-206] Exiting Vivado at Wed Nov  2 23:26:14 2022...
[Project: proj_mlinfn] - [Vivado toolchain - design bitstream end]
```

Accelerator creation

DEMO - Standalone BondMachine creation

DEMO - Standalone BondMachine creation

DEMO - Standalone BondMachine creation

DEMO - Standalone BondMachine creation

```
[ Command > mkdir Example
[ Command > cd Example
[ Command > bmhelper create --project_name mlinfn --board zedboard --project_type neural_network --n
_inputs 4 --n_outputs 3 --source_neuralbond banknote.json
```

DEMO - Standalone BondMachine creation

```
[ Command > mkdir Example
[ Command > cd Example
[ Command > bmhelper create --project_name mlinfn --board zedboard --project_type neural_network --n
_inputs 4 --n_outputs 3 --source_neuralbond banknote.json
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DEMO - Standalone BondMachine creation

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[ Command > mkdir Example
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[ Command > bmhelper create --project_name mlinfn --board zedboard --project_type neural_network --n
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[ Command > cd proj_mlinfn
```

DEMO - Standalone BondMachine creation

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```

DEMO - Standalone BondMachine creation

```
[ Command > mkdir Example
[ Command > cd Example
[ Command > bmhelper create --project_name mlinfn --board zedboard --project_type neural_network --n
_inputs 4 --n_outputs 3 --source_neuralbond banknote.json
[ Command > cd proj_mlinfn
[ Command > cat zedboard_maps.json
```

DEMO - Standalone BondMachine creation

```
[ Command > mkdir Example
[ Command > cd Example
[ Command > bmhelper create --project_name mlinfn --board zedboard --project_type neural_network --n
_inputs 4 --n_outputs 3 --source_neuralbond banknote.json
[ Command > cd proj_mlinfn
[ Command > cat zedboard_maps.json
[ Output  >
{
"Assoc" : {
        "clk" : "clk",
        "reset" : "btnC"
        }
}
```

DEMO - Standalone BondMachine creation

```
[ Command > mkdir Example
[ Command > cd Example
[ Command > bmhelper create --project_name mlinfn --board zedboard --project_type neural_network --n
_inputs 4 --n_outputs 3 --source_neuralbond banknote.json
[ Command > cd proj_mlinfn
[ Command > cat zedboard_maps.json
[ Output  >
{
"Assoc" : {
        "clk" : "clk",
        "reset" : "btnC"
        }
}
[ Command >
make project
make synthesis
make implementation
make bitstream
```

DEMO - Standalone BondMachine creation

```
[ Command > mkdir Example
[ Command > cd Example
[ Command > bmhelper create --project_name mlinfn --board zedboard --project_type neural_network --n
_inputs 4 --n_outputs 3 --source_neuralbond banknote.json
[ Command > cd proj_mlinfn
[ Command > cat zedboard_maps.json
[ Output  >
{
"Assoc" : {
        "clk" : "clk",
        "reset" : "btnC"
        }
}
[ Command >
make project
make synthesis
make implementation
make bitstream
```

Notebook on the board - predictions and correctness

Thanks to PYNQ we can easily load the bitstream and program the FPGA in real time.

With their APIs we interact with the memory addresses of the BM IP to send data into the inputs and read the outputs (not using BM kernel module)

Dump output results for future analysis

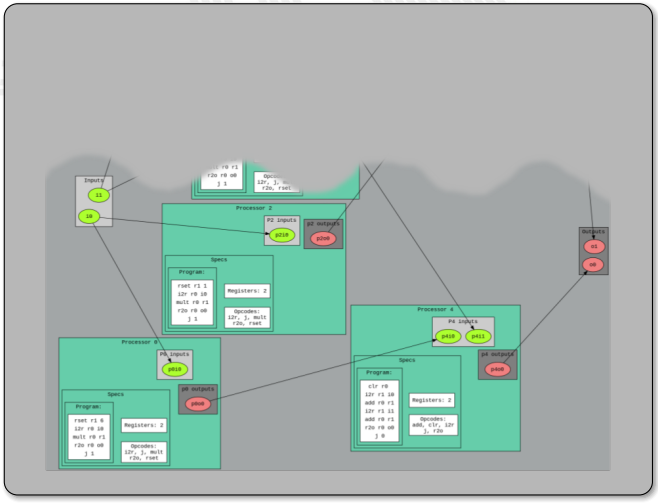
Open the notebook

Benchcore

Benchmark an IP is not an easy task.

Fortunately we have a custom design and an FPGA.

We can put the benchmarks tool inside the accelerator.



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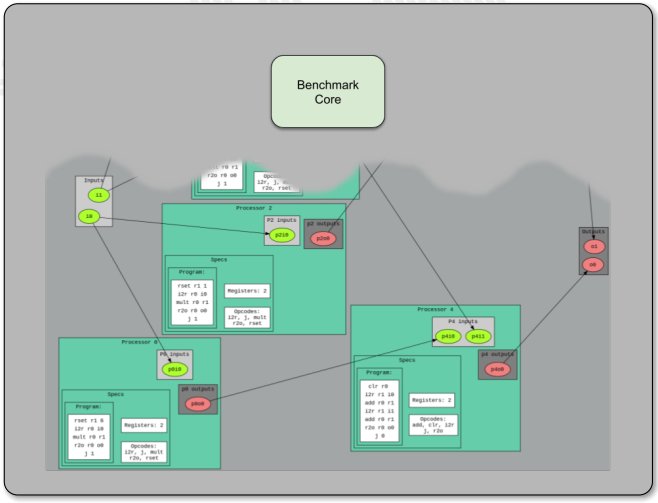

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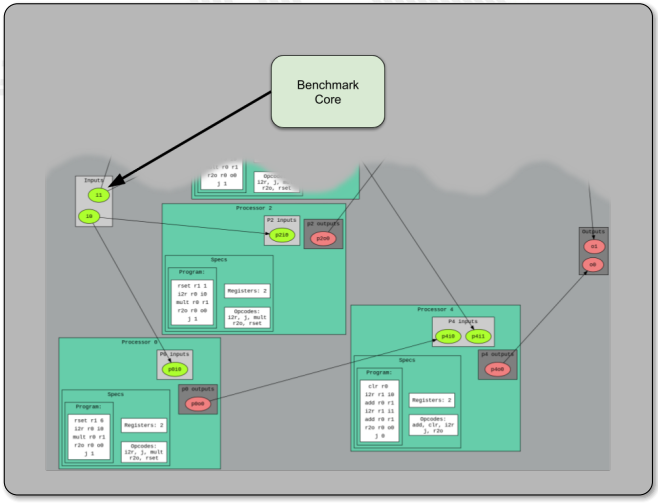

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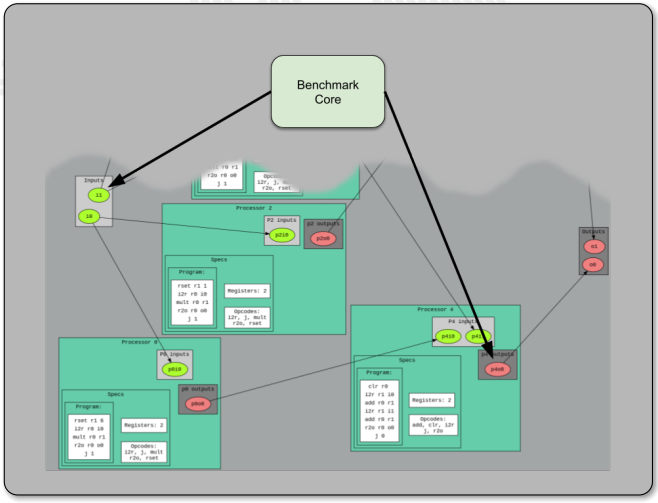

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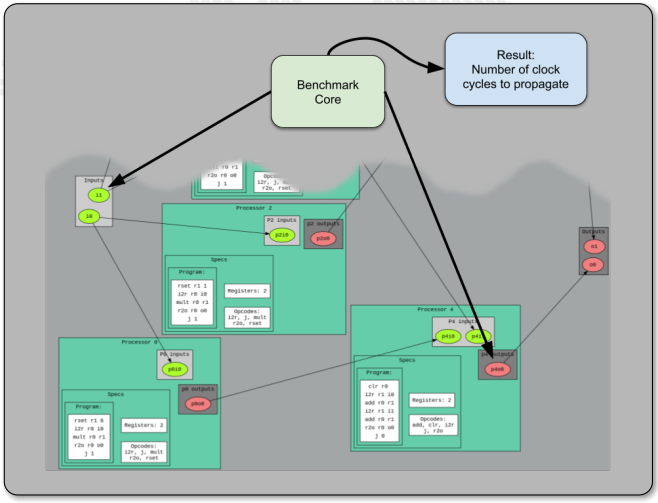
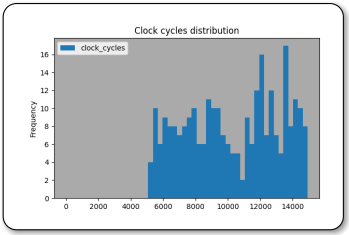


Inference evaluation

Evaluation metrics used:

- **Inference speed**: time taken to predict a sample i.e. time between the arrival of the input and the change of the output measured with the **benchcore**;
- **Resource usage**: luts and registers in use;
- **Accuracy**: as the average percentage of error on probabilities.



- σ: 2875.94
- Mean: 10268.45
- Latency: 102.68 µs

Resource usage

resource	value	occupancy
regs	15122	28.42%
luts	11192	10.51%

Analysis notebook

Another notebook is used to compare runs from different accelerators.

Software

prob0	prob1	class
0.6895	0.3104	0
0.5748	0.4251	0
0.4009	0.5990	1

BondMachine

prob0	prob1	class
0.6895	0.3104	0
0.5748	0.4251	0
0.4009	0.5990	1

The output of the bm corresponds to the software output

Open the notebook

Optimizations

A first example of optimization

Remember the **softmax function**?

$$\sigma(z_i) = \frac{e^{z_i}}{\sum_{j=1}^{N} e^{z_j}}$$

$$e^x = \sum_{l=0}^{K} \frac{x^l}{l!}$$

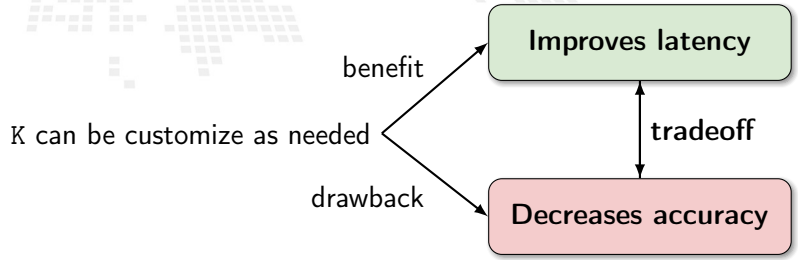
```
%section softmax .romtext iomode:sync
        entry _start    ; Entry point
_start:
 mov r8, 0f0.0
{{range $y := intRange "0" .Params.inputs}}
{{printf "i2r r1,i%d\n" $y}}
        mov     r0, 0f1.0
        mov     r2, 0f1.0
        mov     r3, 0f1.0
        mov     r4, 0f1.0
        mov     r5, 0f1.0
        mov     r7, {{$.Params.expprec}}
loop{{printf "%d" $y}}:
        multf   r2, r1
        multf   r3, r4
        addf    r4, r5
        mov     r6, r2
        divf    r6, r3

        addf    r0, r6

        dec     r7
        jz      r7,exit{{printf "%d" $y}}
        j       loop{{printf "%d" $y}}
exit{{printf "%d" $y}}:
{{$z := atoi $.Params.pos}}
{{if eq $y $z}}
 mov r9, r0
%endsection
```

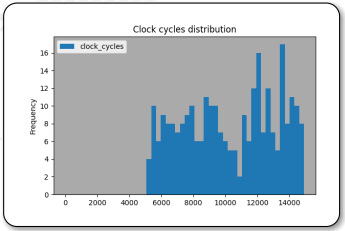
A first example of optimization

$$e^x = \sum_{l=0}^{K} \frac{x^l}{l!}$$



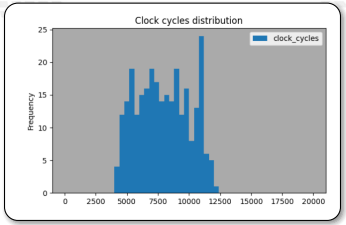
Results of optimization

Changing number of K of the exponential factors in the softmax function...



- K: 20
- σ: 2875.94
- Mean: 10268.45
- Latency: 102 µs
- Prediction: 100%

	mean	σ
prob0	1.6470E-07	1.2332E-07
prob1	1.6623E-07	1.2142E-07

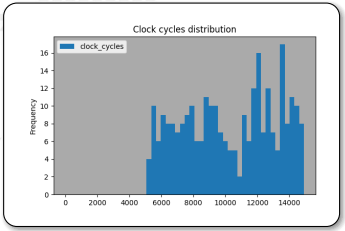


- K: 16
- σ: 2106.32
- Mean: 7946.16
- Latency: 79 µs
- Prediction: 100%

	mean	σ
prob0	1.6470E-07	1.2332E-07
prob1	1.6623E-07	1.2142E-07

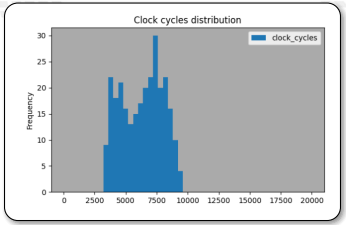
Results of optimization

Changing number of K of the exponential factors in the softmax function...



- K: 20
- σ: 2875.94
- Mean: 10268.45
- Latency: 102 µs
- Prediction: 100%

	mean	σ
prob0	1.6470E-07	1.2332E-07
prob1	1.6623E-07	1.2142E-07

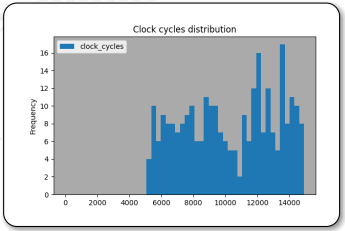


- K: 13
- σ: 1669.88
- Mean: 6312.26
- Latency: 63 µs
- Prediction: 100%

	mean	σ
prob0	1.6470E-07	1.2332E-07
prob1	1.6623E-07	1.2142E-07

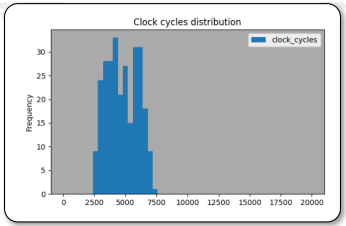
Results of optimization

Changing number of K of the exponential factors in the softmax function...



- K: 20
- σ: 2875.94
- Mean: 10268.45
- Latency: 102 µs
- Prediction: 100%

	mean	σ
prob0	1.6470E-07	1.2332E-07
prob1	1.6623E-07	1.2142E-07

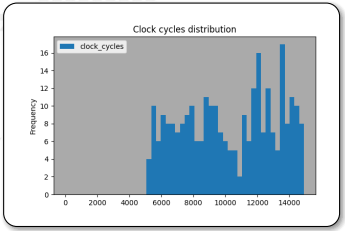


- K: 10
- σ: 1232.47
- Mean: 4766.75
- Latency: 47 µs
- Prediction: 100%

	mean	σ
prob0	1.6162E-07	1.1013E-07
prob1	1.6525E-07	1.1831E-07

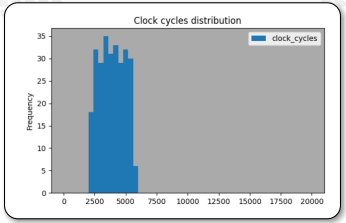
Results of optimization

Changing number of K of the exponential factors in the softmax function...



- K: 20
- σ: 2875.94
- Mean: 10268.45
- Latency: 102 µs
- Prediction: 100%

	mean	σ
prob0	1.6470E-07	1.2332E-07
prob1	1.6623E-07	1.2142E-07

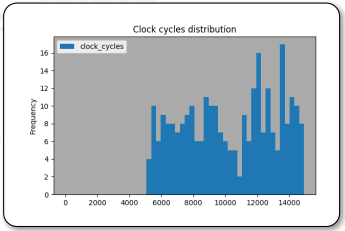


- K: 8
- σ: 1015.50
- Mean: 3913.66
- Latency: 39 µs
- Prediction: 100%

	mean	σ
prob0	6.5562E-05	1.7607E-05
prob1	6.6098E-05	1.7609E-05

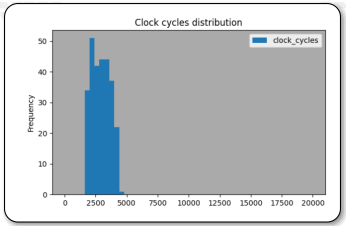
Results of optimization

Changing number of K of the exponential factors in the softmax function...



- K: 20
- σ: 2875.94
- Mean: 10268.45
- Latency: 102 µs
- Prediction: 100%

	mean	σ
prob0	1.6470E-07	1.2332E-07
prob1	1.6623E-07	1.2142E-07

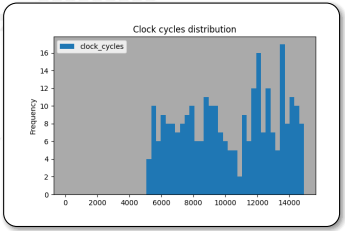


- K: 5
- σ: 740
- Mean: 2911
- Latency: 29 µs
- Prediction: 100%

	mean	σ
prob0	3.1070E-05	7.5290E-05
prob1	3.1070E-05	7.5290E-05

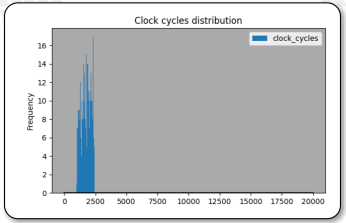
Results of optimization

Changing number of K of the exponential factors in the softmax function...



- K: 20
- σ: 2875.94
- Mean: 10268.45
- Latency: 102 µs
- Prediction: 100%

	mean	σ
prob0	1.6470E-07	1.2332E-07
prob1	1.6623E-07	1.2142E-07

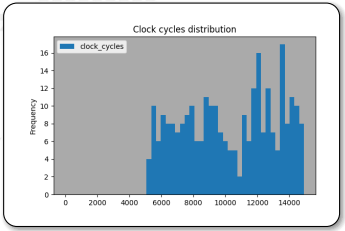


- K: 3
- σ: 394.10
- Mean: 1750.93
- Latency: 17 µs
- Prediction: 100%

	mean	σ
prob0	0.0053	0.0090
prob1	0.0053	0.0090

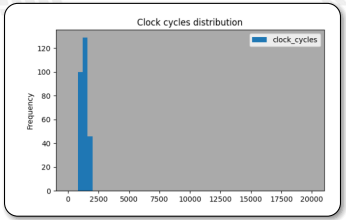
Results of optimization

Changing number of K of the exponential factors in the softmax function...



- K: 20
- σ: 2875.94
- Mean: 10268.45
- Latency: 102 µs
- Prediction: 100%

	mean	σ
prob0	1.6470E-07	1.2332E-07
prob1	1.6623E-07	1.2142E-07

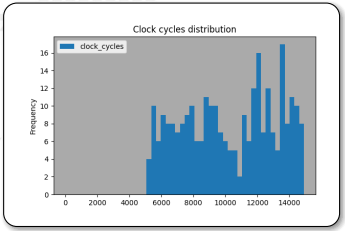


- K: 2
- σ: 268.69
- Mean: 1311.11
- Latency: 13.11 µs
- Prediction: 100%

	mean	σ
prob0	0.0193	0.0232
prob1	0.0193	0.0232

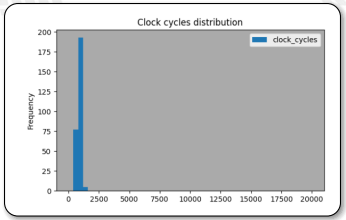
Results of optimization

Changing number of K of the exponential factors in the softmax function...



- K: 20
- σ: 2875.94
- Mean: 10268.45
- Latency: 102 µs
- Prediction: 100%

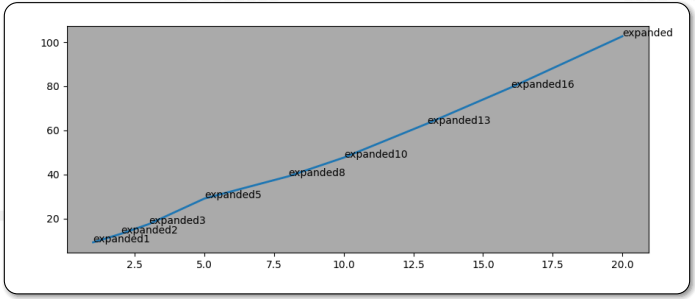
	mean	σ
prob0	1.6470E-07	1.2332E-07
prob1	1.6623E-07	1.2142E-07



- K: 1
- σ: 173.25
- Mean: 923.71
- Latency: 9.23 µs
- Prediction: 100%

	mean	σ
prob0	0.0990	0.1641
prob1	0.0990	0.1641

Results of optimization

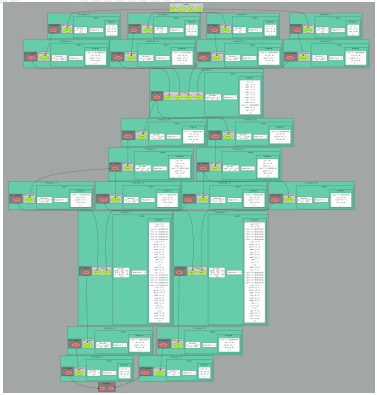


K	**Inference time**
1	9.23 µs
2	13.11 µs
3	17.50 µs
5	29.11 µs
8	39.13 µs
10	47.66 µs
13	63.12 µs
16	79.46 µs
20	102.68 µs

Reduced inference times by a factor of 10 ... only by decreasing the number of iterations.

Fragments composition

- The tools (neuralbond+basm) create a graph of relations among fragments of assembly
  - Not necessarily a fragment has to be mapped to a single CP
  - They can arbitrarily be rearranged into CPs
  - The resulting firmwares are identical in term of the computing outcome, but differs in occupancy and latency.



Let see it live

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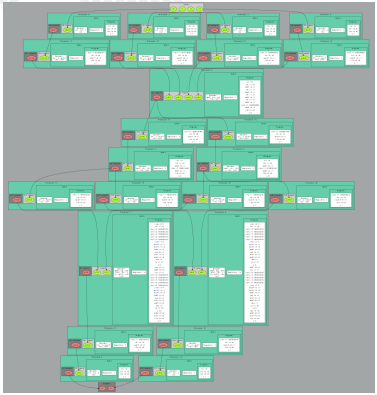

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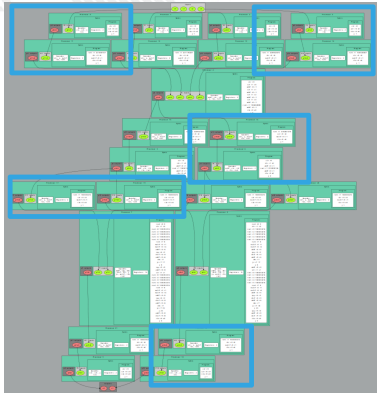

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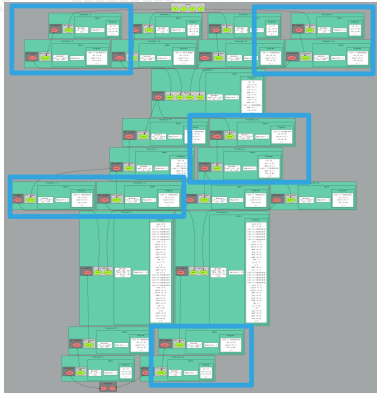

Let see it live

Several ways for customization and optimization

The great control over of the architectures generated by the BondMachine gives several possible optimizations.

- Mixing hardware and software optimizations
- CP Pruning and/or collapsing
- Fabric independent
- HW instructions swapping
- Fine control over occupancy vs latency
- Fragment composition
- HW/SW Templates
- Software based functions

Conclusions and Future directions

Conclusions and Future directions

With ML we are still at the beginning ...

- **More datasets**: test on other datasets with more features and multiclass classification;
- **Neurons**: increase the library of neurons to support other activation functions;
- **Boards**: support for more boards of different vendors;
- **Evaluate results**: compare the results obtained with other technologies (CPU and GPU) in terms of inference speed and energy efficiency;

Thank you

website: `http://bondmachine.fisica.unipg.it`
code: `https://github.com/BondMachineHQ`
parallel computing paper: link
contact email: mirko.mariotti@unipg.it