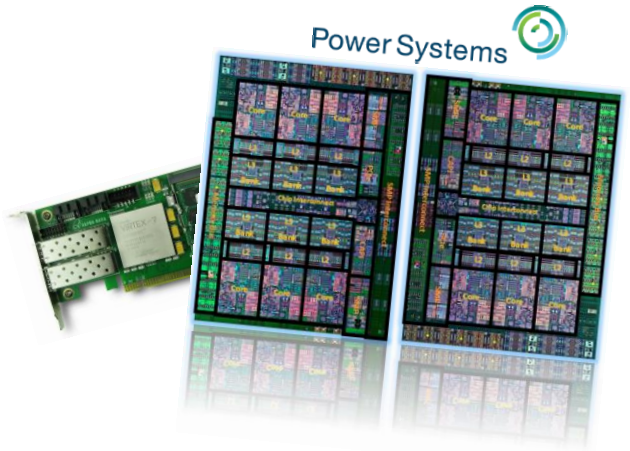
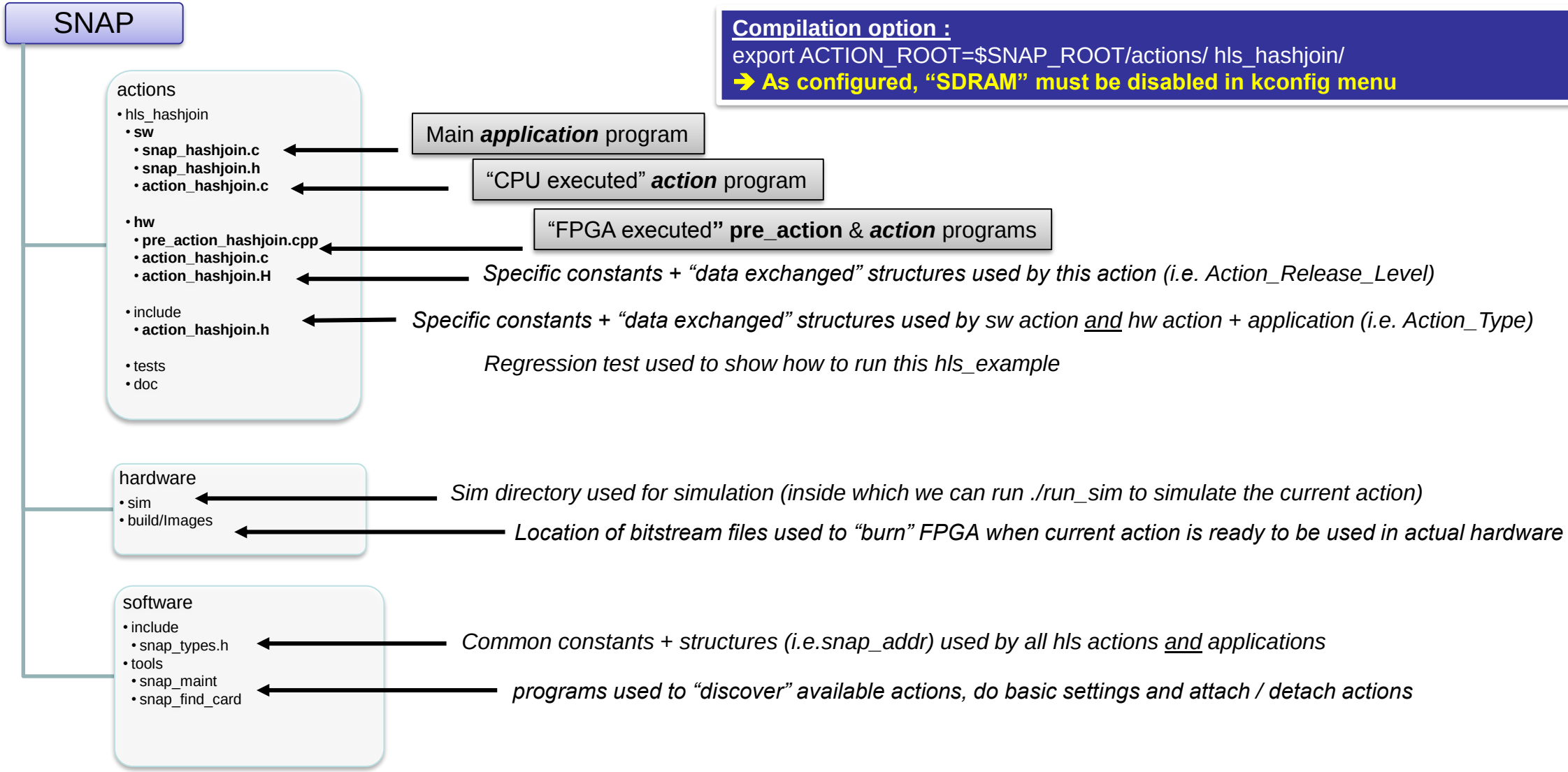
CAPI SNAP Education Series:
User Guide

!! Sometimes building image fails (timing issue)
=> Need code change to prevent this !!

CAPI SNAP Education
hls_hashjoin : howto?
V2.1



Architecture of the SNAP git files



Action overview

Purpose: Port a hashjoin function

- **Evaluate how tables can be managed with HLS**
- **Compare CPU and FPGA performances**

When to use it:

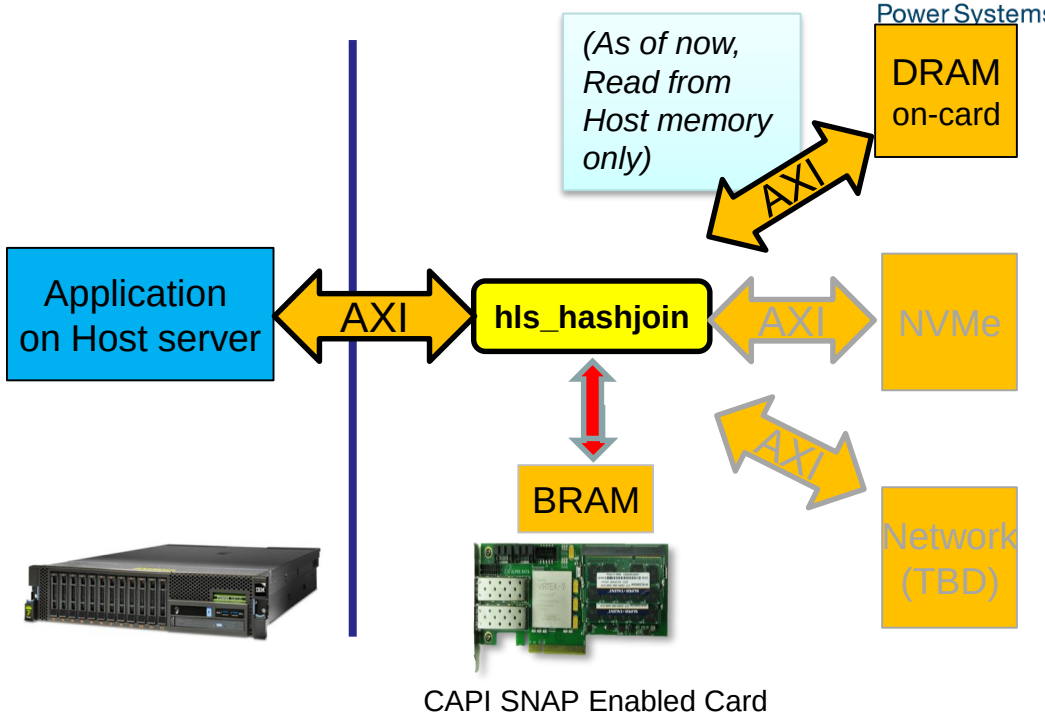
- Understand HLS constraints when working with large database

Memory management:

- All memory allocation is managed by the application

Known limitations:

- All data are 64 bytes aligned to ease access
- Data taken from Host memory instead of DDR




```
typedef struct table1_s {
        hashkey_t name;         /* 64 bytes */
        uint32_t age;           /*  4 bytes */
        uint8_t reserved[60];   /* 60 bytes */
} table1_t;
```

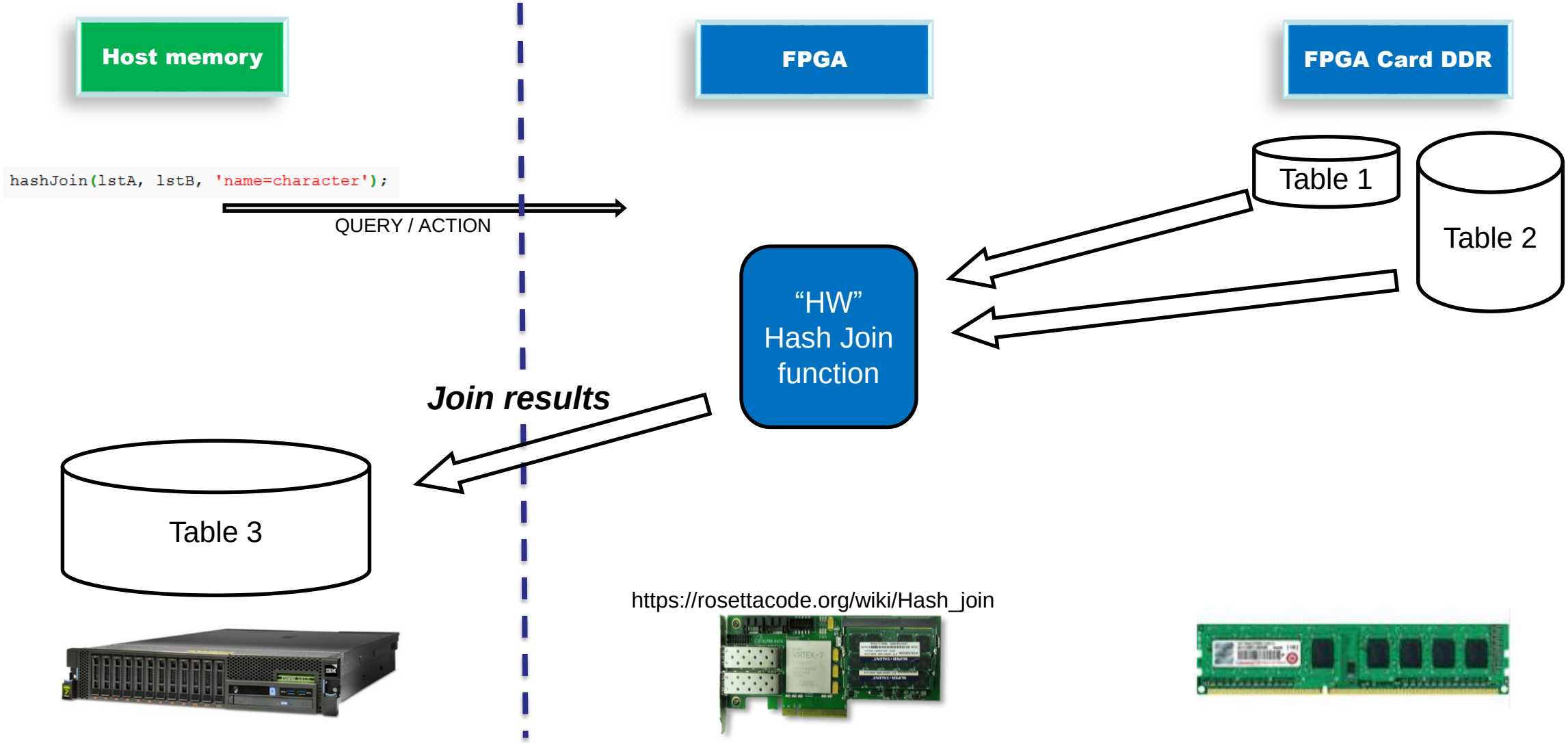
Hashjoin…an example

```
table1_t table1[] = {
  { .name = "Markus", .age=93 }          /* 0. */
  { .name = "Frank", .age=51 }           /* 1. */
  { .name = "George W.", .age=94 }       /* 2. */
  { .name = "Tercia", .age=63 }          /* 3. */
  { .name = "Secunda", .age=32 }         /* 4. */
  { .name = "Susanne", .age=99 }         /* 5. */
  { .name = "Tercia", .age=37 }          /* 6. */
  { .name = "Thomas", .age=71 }          /* 7. */
  { .name = "Joerg-Stephan", .age=89 }   /* 8. */
  { .name = "Lisa", .age=47 }            /* 9. */
  { .name = "Julius", .age=75 }          /* 10. */
  { .name = "Glory", .age=83 }           /* 11. */
  { .name = "Melanie", .age=24 }         /* 12. */
  { .name = "Quintus", .age=77 }         /* 13. */
  { .name = "Prima", .age=52 }           /* 14. */
  { .name = "Andreas", .age=12 }         /* 15. */
  { .name = "Tercitus", .age=39 }        /* 16. */
  { .name = "Anders", .age=51 }          /* 17. */
  { .name = "Alexander", .age=38 }       /* 18. */
  { .name = "Dieter", .age=57 }          /* 19. */
  { .name = "Susanne", .age=48 }         /* 20. */
  { .name = "Melanie", .age=44 }         /* 21. */
  { .name = "Uwe", .age=50 }             /* 22. */
  { .name = "Jonah", .age=16 }           /* 23. */
  { .name = "Septus", .age=20 }          /* 24. */
}; /* table1_idx=25
```

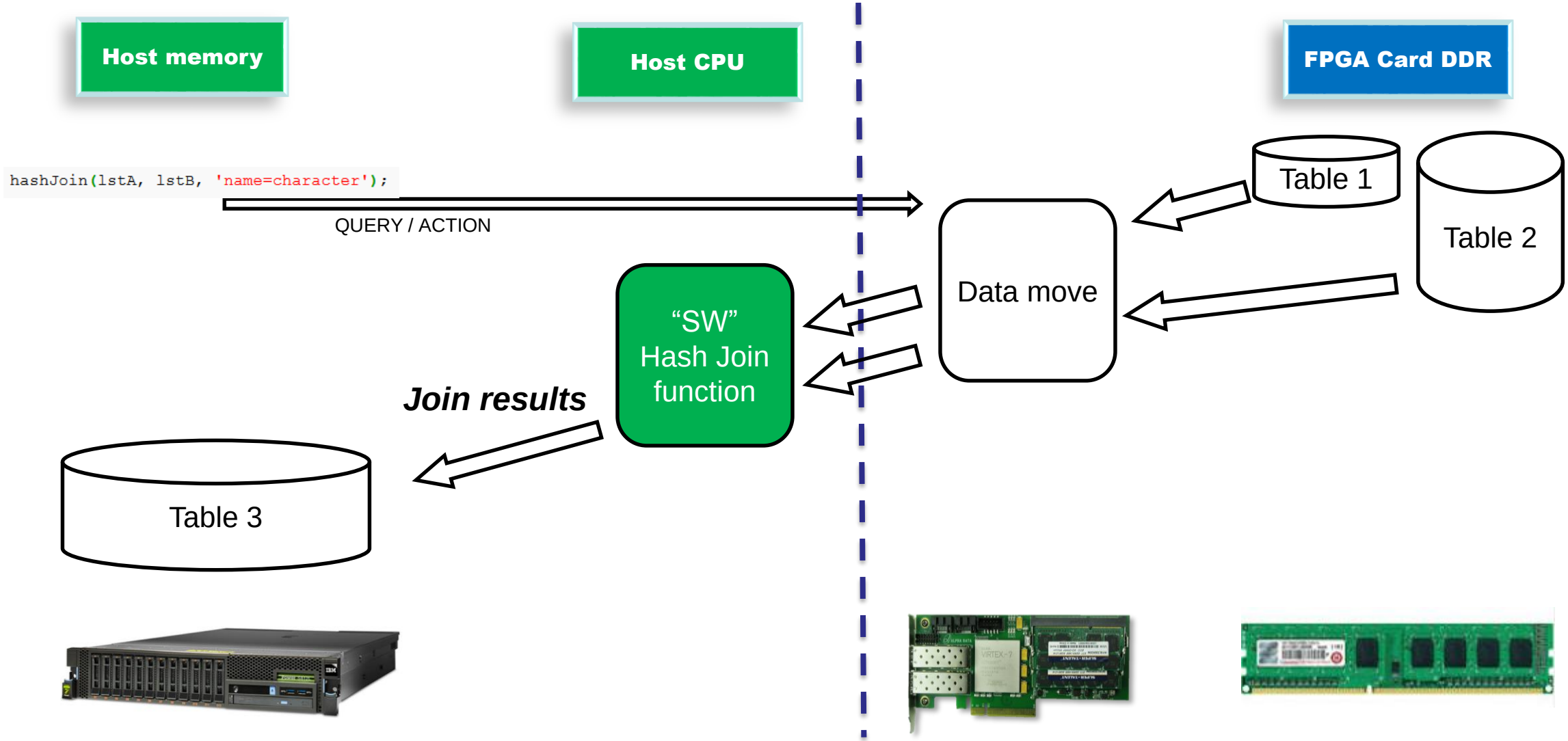
```
table2_t table2[] = {
  { .name = "Dirk", .animal = "Gorilla" }              /* 0. */
  { .name = "Jonah", .animal = "Cat" }                 /* 1. */
  { .name = "Horst", .animal = "Eagle" }               /* 2. */
  { .name = "Eberhard", .animal = "Dog" }              /* 3. */
  { .name = "Eberhard", .animal = "Elephant" }         /* 4. */
  { .name = "Quintus", .animal = "Greyling" }          /* 5. */
  { .name = "Septa", .animal = "Gorilla" }             /* 6. */
  { .name = "Mike", .animal = "Pike" }                 /* 7. */
  { .name = "Maik", .animal = "Eagle" }                /* 8. */
  { .name = "George W.", .animal = "Cat" }             /* 9. */
  { .name = "Septus", .animal = "Goose" }              /* 10. */
  { .name = "Andrea", .animal = "Ghost" }              /* 11. */
  { .name = "Susanne", .animal = "Antilope" }          /* 12. */
  { .name = "Glory", .animal = "Trout" }               /* 13. */
  { .name = "Septa", .animal = "Dog" }                 /* 14. */
  { .name = "Prima", .animal = "Cat" }                 /* 15. */
  { .name = "Quintus", .animal = "Antilope" }          /* 16. */
  { .name = "Mike", .animal = "Elephant" }             /* 17. */
  { .name = "Primus", .animal = "Goose" }              /* 18. */
  { .name = "Lisa", .animal = "Panther" }              /* 19. */
  { .name = "Glory", .animal = "Gepard" }              /* 20. */
  { .name = "Bruno", .animal = "Dog" }                 /* 21. */
  { .name = "Septa", .animal = "Antilope" }            /* 22. */
}; /* table2_idx=23
```

```
table3_t table3[] = {
  { .name = "Jonah", .animal = "Cat", .age=16 }        /* 0. */
  { .name = "Quintus", .animal = "Greyling", .age=77 } /* 1. */
  { .name = "George W.", .animal = "Cat", .age=94 }    /* 2. */
  { .name = "Septus", .animal = "Goose", .age=20 }     /* 3. */
  { .name = "Susanne", .animal = "Antilope", .age=99 } /* 4. */
  { .name = "Susanne", .animal = "Antilope", .age=48 } /* 5. */
  { .name = "Glory", .animal = "Trout", .age=83 }      /* 6. */
  { .name = "Prima", .animal = "Cat", .age=52 }        /* 7. */
  { .name = "Quintus", .animal = "Antilope", .age=77 } /* 8. */
  { .name = "Lisa", .animal = "Panther", .age=47 }     /* 9. */
  { .name = "Glory", .animal = "Gepard", .age=83 }     /* 10. */
}; /* table3_idx=11
```

Hash Join : data are in card DDR - processing done in FPGA



Hash Join : data are in card DDR - processing done in CPU



Action usage

Usage:

```
./snap_hashjoin -usage
Usage: ./snap_hashjoin [-h] [-v, --verbose] [-V, --version]
  -C, --card <cardno> can be (0...3)
  -t, --timeout <timeout>  Timefor for job completion. (default 10 sec)
  -Q, --t1-entries <items> Entries in table1. (maximum TABLE1_SIZE defined in snap/software/examples/action_hashjoin.h)
  -T, --t2-entries <items> Entries in table2.
  -s, --seed <seed>        Random seed to enable recreation.
  -N, --no irq             Disable IRQs
```

Example :

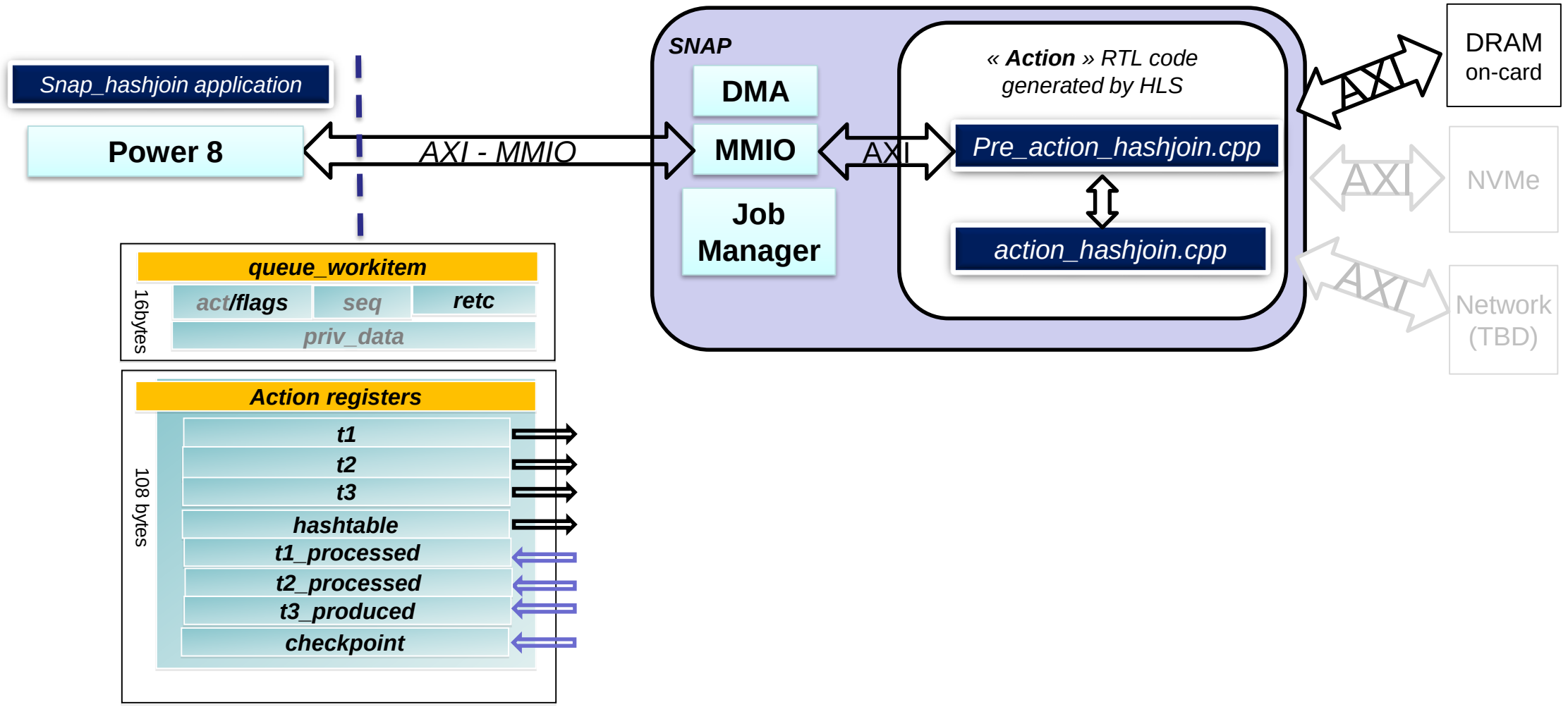
```
export SNAP_TRACE=0x0
$SNAP_ROOT/software/tools/snap_maint

#echo Random generation of 2 tables with default table size (T1 = 25 entries / T2 = 23 entries)
SNAP_CONFIG=CPU ./snap_hashjoin -C1 -vv -t2500
#echo Random generation of 2 tables with 30 entries for T1 and 60 for T2 => action will call 2 times the action
SNAP_CONFIG=CPU ./snap_hashjoin -C1 -vv -t2500 -Q 30 -T 60
```

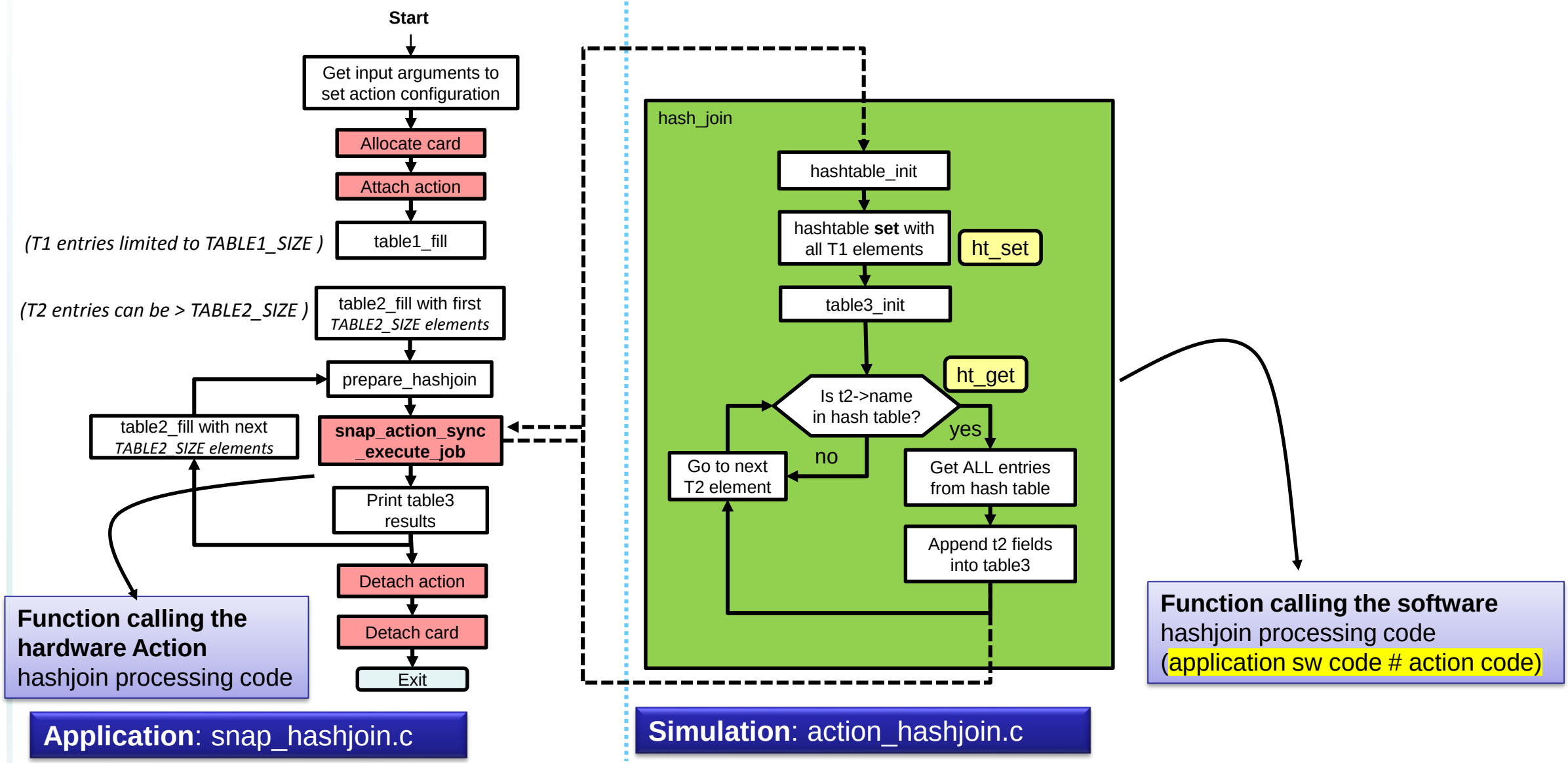
Options:

```
SNAP_TRACE = 0x0 ➔ no debug trace
SNAP_TRACE = 0xF ➔ full debug trace
SNAP_CONFIG = FPGA➔ hardware execution
SNAP_CONFIG = CPU ➔ software execution
```

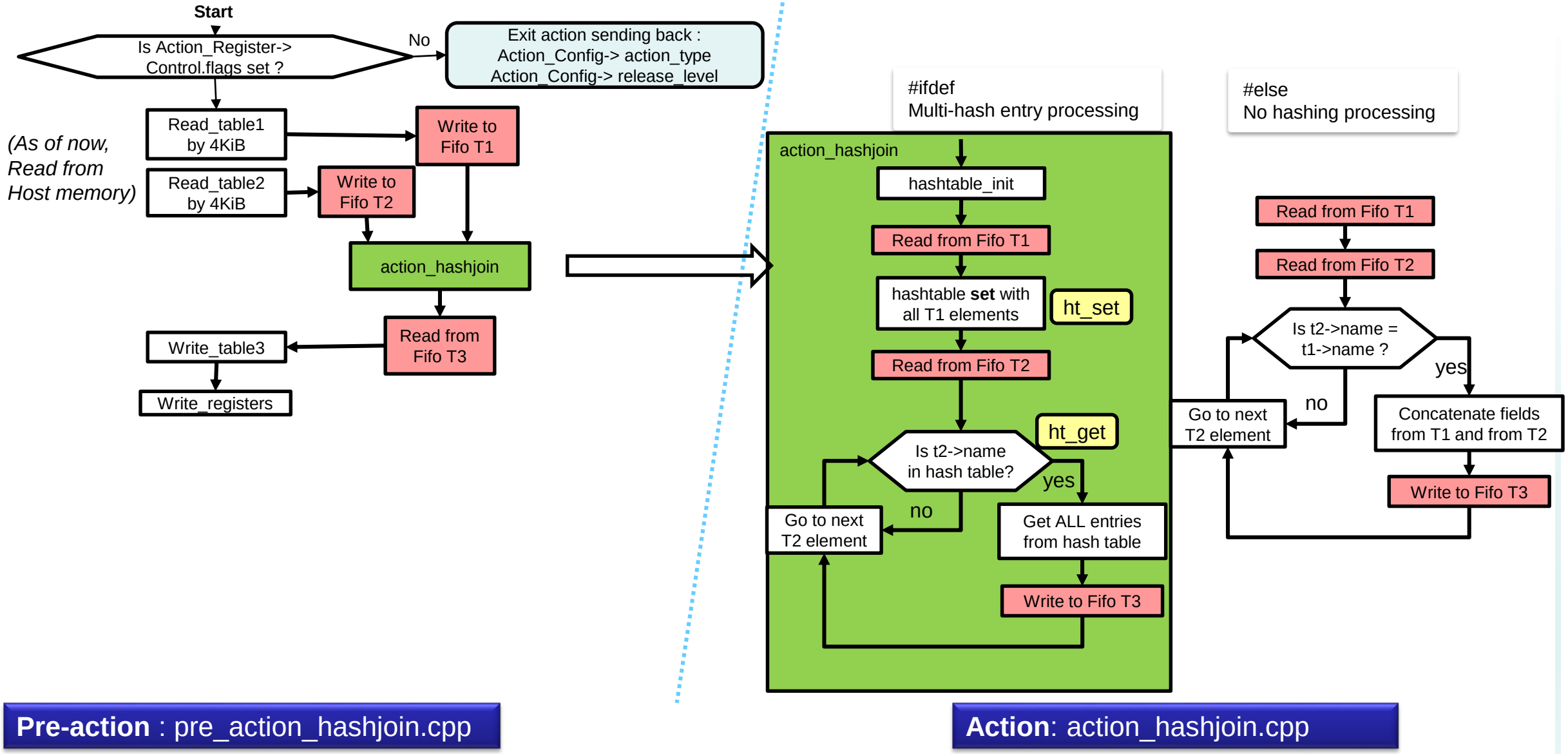
Hashjoin registers



Application Code : what's in it?



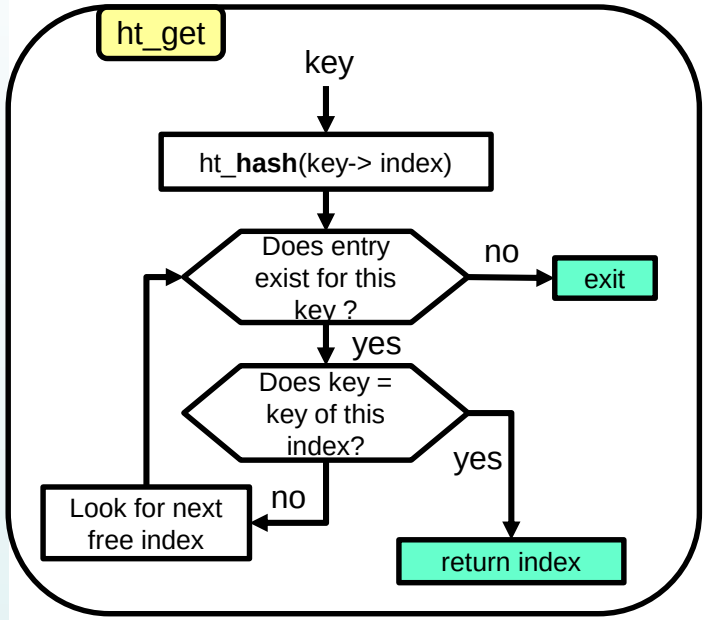
Action hashjoin Code : what's in it?

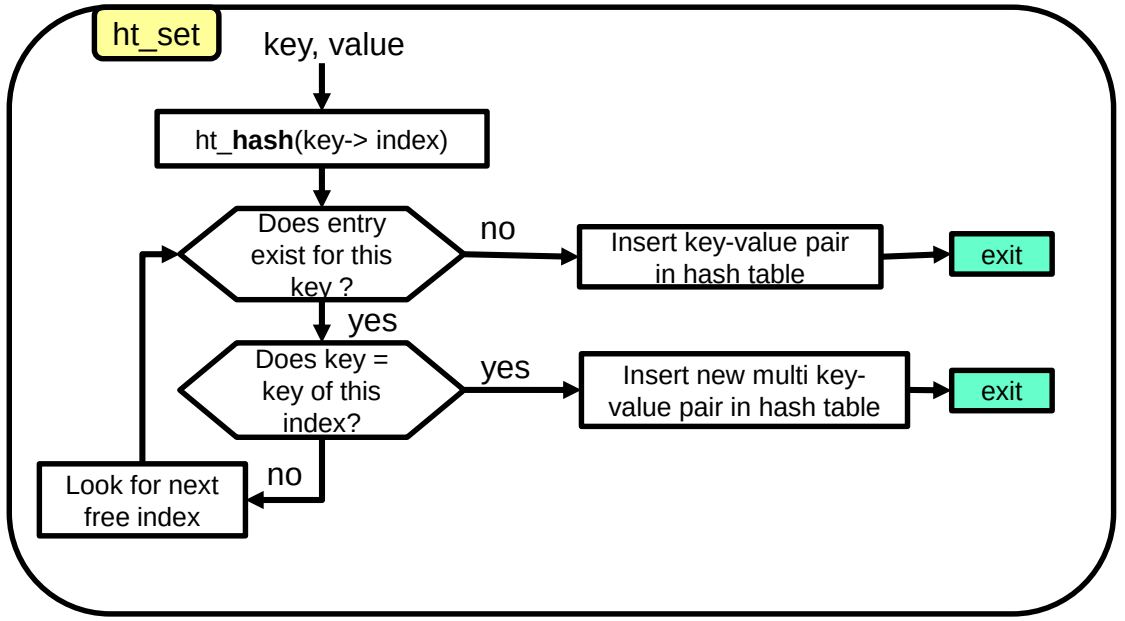


Pre-action : pre_action_hashjoin.cpp

Action: action_hashjoin.cpp

Application - Action hashjoin Code : what's in it?





CPU Action : action_hashjoin.c / FPGA Action: action_hashjoin.cpp

Constants - Ports

Constants: ➔ $ACTION_ROOT = snap/actions/hls_hashjoin

Constant name	Value	Type	Definition location	Usage
HASHJOIN_ACTION_TYPE	0x10141002	Fixed	$ACTION_ROOT/include/action_hashjoin.h	Checksum ID - list is in snap/ActionTypes.md
RELEASE_LEVEL	0x00000021	Variable	$ACTION_ROOT/hw/action_hashjoin.**H**	release level – user defined
TABLE1_SIZE	32	Variable	$ACTION_ROOT/hw/action_hashjoin.**H**	Maximum number of entries for Table1
TABLE2_SIZE	32	Variable	$ACTION_ROOT/hw/action_hashjoin.**H**	Maximum size of the Table 2 for the hardware action, but entries can be from any size. Multiple calls to Action will return table3 results
TABLE3_SIZE	(TABLE1_SIZE * TABLE2_SIZE)	*Operation*	$ACTION_ROOT/hw/action_hashjoin.**H**	Table 3 will be from any size
HT_SIZE	(TABLE1_SIZE * 16)	*Operation*	$ACTION_ROOT/hw/action_hashjoin.**H**	Definition of the size of hashtable
HT_MULTI	(TABLE1_SIZE)	*Operation*	$ACTION_ROOT/hw/action_hashjoin.**H**	multihash entries depends on table1

Ports used:

Ports name	Description	Enabled
din_gmem	Host memory data bus input Addr : 64bits - Data : 512bits	Yes
dout_gmem	Host memory data bus output Addr : 64bits - Data : 512bits	Yes
d_ddrmem	DDR3 - DDR4 data bus in/out Addr : 33bits - Data : 512bits	No
nvme	NVMe data bus in/out Addr : 32bits - Data : 32bits	*No (soon)*

MMIO Registers

Read and Write are considered from the application / software side

act_reg.Control CONTROL		This header is initialized by the SNAP job manager. The action will update the Return code and read the flags value. If the flags value is 0, then action sends only the action_RO_config_reg value and exit the action, otherwise it will process the action						
Simu - WR	Write@	Read@	3	2	1	0	Typical Write value	Typical Read value
0x3C40	0x100	0x180	sequence		**flags**	short action type	f001_01_00	
0x3C41	0x104	0x184	**Retc** (return code 0x102/0x104)				0	0x102 - 0x104 SUCCESS/FAILURE
0x3C42	0x108	0x188	Private Data				c0febabe	
0x3C43	0x10C	0x18C	Private Data				deadbeef	

action_reg.Data hashjoin_job_t		Action specific - user defined - need to stay in 108 Bytes(padding done in $ACTION_ROOT/hw/action_hashjoin.H) This is the way for application and action to exchange information through this set of registers					
Simu - WR	Write@	Read@	3	2	1	0	Typical Write valu
0x3C44	0x110	0x190	[snap_addr]**t1**.addr (LSB)				
0x3C45	0x114	0x194	[snap_addr]**t1**.addr (MSB)				
0x3C46	0x118	0x198	[snap_addr]**t1**.size				
0x3C47	0x11C	0x19C	[snap_addr]**t1**.flags (SRC, DST, ...)		[snap_addr]**t1**.type (DRAM, NVME,..)		
0x3C48	0x120	0x1A0	[snap_addr]**t2**.addr (LSB)				
0x3C49	0x124	0x1A4	[snap_addr]**t2**.addr (MSB)				
0x3C4A	0x128	0x1A8	[snap_addr]**t2**.size				
0x3C4B	0x12C	0x1AC	[snap_addr]**t2**.flags (SRC, DST, ...)		[snap_addr]**t2**.type (DRAM, NVME,..)		
0x3C4C	0x130	0x1B0	[snap_addr]**t3**.addr (LSB)				
0x3C4D	0x134	0x1B4	[snap_addr]**t3**.addr (MSB)				
0x3C4E	0x138	0x1B8	[snap_addr]**t3**.size				
0x3C4F	0x13C	0x1BC	[snap_addr]**t3**.flags (SRC, DST, ...)		[snap_addr]**t3**.type (DRAM, NVME,..)		
0x3C50	0x140	0x1C0	[snap_addr]**hashtable**.addr (LSB)				
0x3C51	0x144	0x1C4	[snap_addr]**hashtable**.addr (MSB)				
0x3C52	0x148	0x1C8	[snap_addr]**hashtable**.size				
0x3C53	0x14C	0x1CC	[snap_addr]**hashtable**.flags (SRC, DST, ...)		[snap_addr]**hashtable**.type (DRAM, NVM		
0x3C54	0x150	0x1D0	t1_processed				
0x3C55	0x154	0x1D4	t2_processed				
0x3C56	0x158	0x1D8	t3_produced				
0x3C57	0x15C	0x1DC	checkpoint				

$ACTION_ROOT/hw/action_hashjoin.H

```
typedef struct {
    CONTROL Control;       /*  16 bytes */
    hashjoin_job_t Data;    /* 108 bytes */
    uint8_t padding[SNAP_HLS_JOBSIZE - sizeof(hashjoin__job_t)];
} action_reg;
```

$ACTION_ROOT/include/action_hashjoin.h

```
typedef struct hashjoin_job {
    struct snap_addr t1; /* IN: input table1 for multihash */
    struct snap_addr t2; /* IN: 2nd table2 to do join with */
    struct snap_addr t3; /* OUT: resulting table3 */
    struct snap_addr hashtable; /* CACHE: multihash table */

    uint64_t t1_processed; /* #entries cached, repeat if not all */
    uint64_t t2_processed; /* #entries processed, repeat if not all */
    uint64_t t3_produced;  /* #entries produced store them away */
    uint64_t checkpoint;
} hashjoin_job_t;
```

$SNAP_ROOT/actions/include/hls_snap.H

```
typedef struct {
    snapu8_t sat; // short action type
    snapu8_t flags;
    snapu16_t seq;
    snapu32_t Retc;
    snapu64_t Reserved; // Priv_data
} CONTROL;
```

$SNAP_ROOT/software/include/snap_types.h

```
typedef struct snap_addr {
    uint64_t addr;
    uint32_t size;
    snap_addrtype_t type;        /* DRAM, NVME, ... */
    snap_addrflag_t flags;       /* SRC, DST, EXT, ... */
} snap_addr_t;
```

Measured performance

Times are in µs			"SW" hashjoin process (on CPU)			"HW" hashjoin process (on FPGA)						
2x64B	2x64B						1/2 of T2	3x64B			1/2 of T2	1/4 of T2
T1 (entries)	T2 (entries)	T1+T2 Size(Bytes)	DDR to Host	SW	Total	HW	T3 (entries)	Size in Bytes	DDR to Host	Total	Avg Speed up	Avg Speed up
30	50	10,240	7,314	511	7,825	241	25	4,800	3,429	3,670	2.1	4.1
30	500	67,840	48,457	1,014	49,471	1,318	250	48,000	34,286	35,604	1.4	2.7
30	5,000	643,840	459,886	5,132	465,018	12,222	2,500	480,000	342,857	355,079	1.3	2.5
30	50,000	6,403,840	4,574,171	34,493	4,608,664	114,813	25,000	4,800,000	3,428,571	3,543,384	1.3	2.5

For this performance measurement, we considered :

- 2 tables in entries containing each 2 x 64Bytes fields
- 1 table for results containing 3 x 64Bytes fields
- ***We considered that results are ½ of the number of the entries of the largest table (realistic ?)***

Comment : No real optimization work was done on this example since hash logic may need to be modified to build the image an easier way

What else ?

Path of improvement ?

1. Find how write the algorithm so that HLS can parallelize :
    - Building hashtable with new elements from table 1 (small table)
    - Checking / adding new elements from table 2 (large table)
    - Filling result table 3

    ➔ This mean handling collision
2. Enable conversion/type-casting of flat memory to structures
3. Support unaligned data access e.g. special FIFOs
4. Pointers, dynamic memory allocation, ...

Backup slides

Experiences during implementation

CAPI should allow direct access to host-memory. But ...

1. Simple conversion (e.g. casting) from void */uint8_t * to struct table_t *data do not work
   ***Circumvention**: manual data conversion*

```
static void read_table1(snap_membus_t *mem, unsigned int max_lines,
            t1_fifo_t *fifo1, uint32_t t1_used)
{
      unsigned int i;
      snap_4KiB_t buf;

      snap_4KiB_rinit(&buf, mem, max_lines);
read_table1_loop:
      for (i = 0; i < t1_used; i++) {
#pragma HLS PIPELINE
            snap_membus_t b[2];
            table1_t t1;

            snap_4KiB_get(&buf, &b[0]);
            copy_hashkey(b[0], t1.name);
            snap_4KiB_get(&buf, &b[1]);
            t1.age = b[1](31, 0);
            fifo1->write(t1)
      }
}
```

Would like to have something alike:

```
      table1_t t1[16];
      memcopy(&t1, (hmem_axi_bus + t1_offs), sizeof(t1));

Or even better:

      table1_t *t1 = (table1_t *)(hmem_axi_bus + t1_addr);
```

… more

2. SNAP 512 bit fixed width bus causes code complexity when handling unaligned data – currently no helper support
   ***Circumvention**: align and pad data to 512 bit boundaries to keep code simple, transfer more data than needed if code complexity should be low*
   ***Future**: Maybe the AXI_to_table FIFO?*
   ***Impact :** More data-movement complexity to avoid transferring additional data, no possibility in HLS to write preceding bytes (we do not own those)*

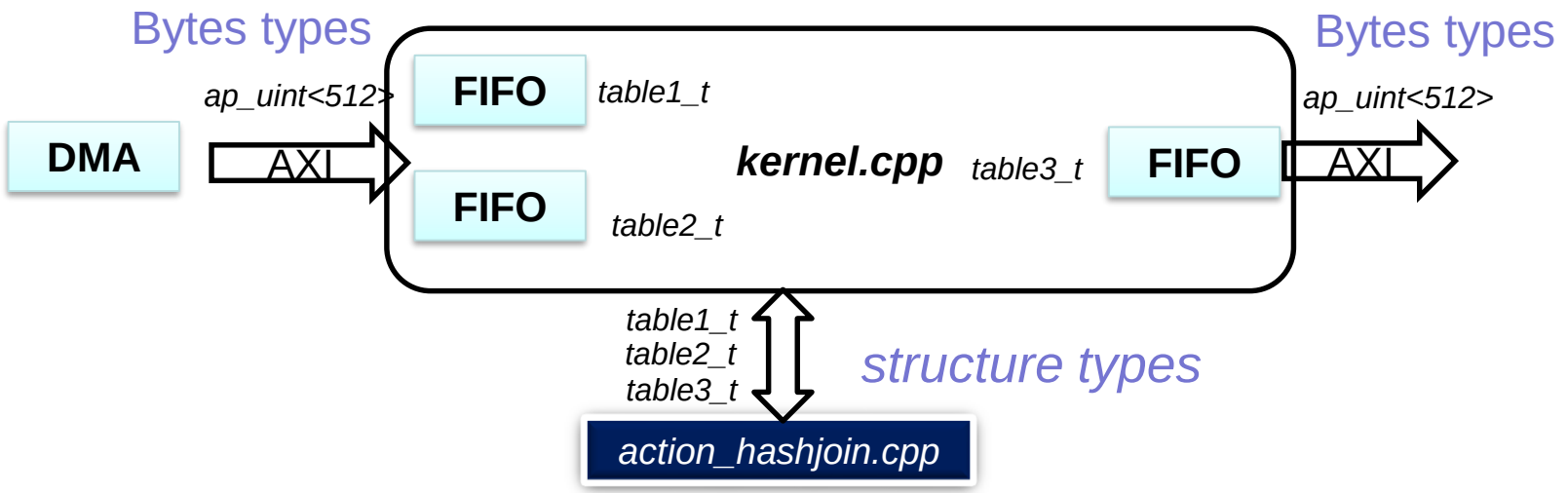
```
typedef struct table1_s {
        hashkey_t name;             /* 64 bytes */
        unsigned int age;           /*  4 bytes */
        unsigned char reserved[60]; /* 60 bytes */
} table1_t;

typedef struct table2_s {
        hashkey_t name;             /* 64 bytes */
        hashkey_t animal;           /* 64 bytes */
} table2_t;

typedef struct table3_s {
        hashkey_t animal;           /* 64 bytes */
        hashkey_t name;             /* 64 bytes */
        unsigned int age;           /*  4 bytes */
        unsigned char reserved[60]; /* 60 bytes */
} table3_t;
```

Suggestions to solve items 1 & 2 : use FIFO to cast types

- Connect a FIFO between the AXI bus and the action_hashjoin function ➔ DONE
- Build with MIG / Memory Interface Generator a FIFO which has following characteristics: ➔ EXIST
  - Input data bus width is fixed to 512 bits/64B
  - Output data bus width will be adapted to the action (e.g. 32B/64B/128Bytes)
  - Depth of FIFO can absorb the 4KiB required by PSL access
- Call this FIFO in C program such that it can be integrated by HLS ➔ **MISSING**
- Use FIFO to do type casting : ap_uint in input and structure in output ➔ **MISSING**



… more

3. Complex pointer operations are not possible, e.g. dynamic memory management, pointer lists, etc.
   Circumvention: Rewrite the code

   Maybe: Special allocators for fixed size objects? E.g. in external onboard DDR memory. Simplistic cache?

History of this document and of the action release level

V2.0: initial document
V2.1: new files directory structure applied