Agile and dynamic functional coverage using SQL on the cloud

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Introduction

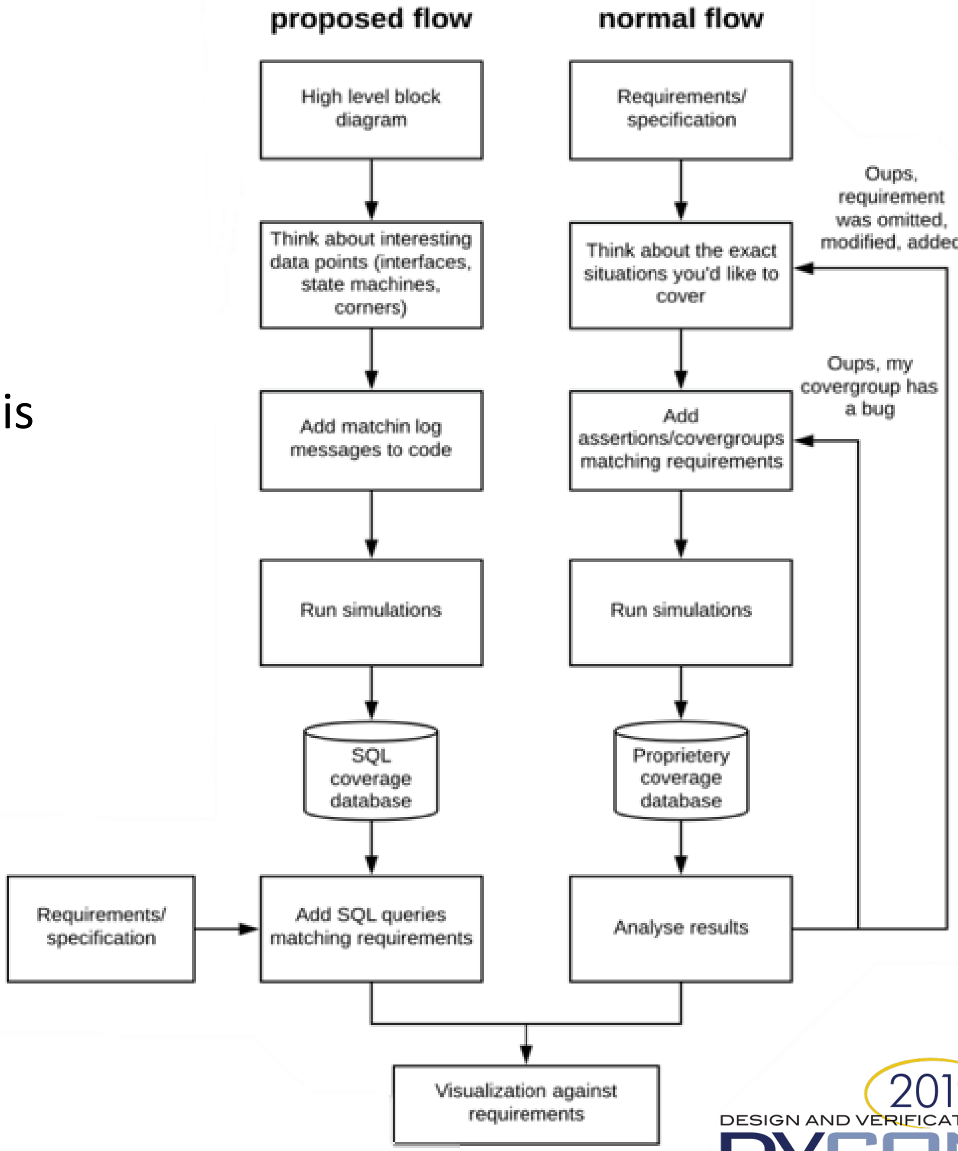
- Functional coverage a key metric in most verification project
- Used often to “drive” the verification process
- decoupled and abstracted from the design
- suffers a few major shortcomings
  - Hardly portable to anything outside SV running on a hardware simulator
  - Can’t be changed in light of the results
  - No adding new cover points after running
  - way too static, platform limited, and costly to implement

Functional Coverage

- Coverage collection vs coverage visualization
- Verification plan document linked to coverage results very convincing
- UCIS standard - interoperability of verification coverage data across multiple tools
- Proposed solution addresses coverage collection shortcomings
  - by using log files as the raw data
  - allow coverage to be collected from any language/platform combination
  - by using a standard SQL to process the data
  - enabling exploration, refinement, and even queries that combine data and sequences of events
  - leveraging UCIS can be integrated with any other sources of coverage

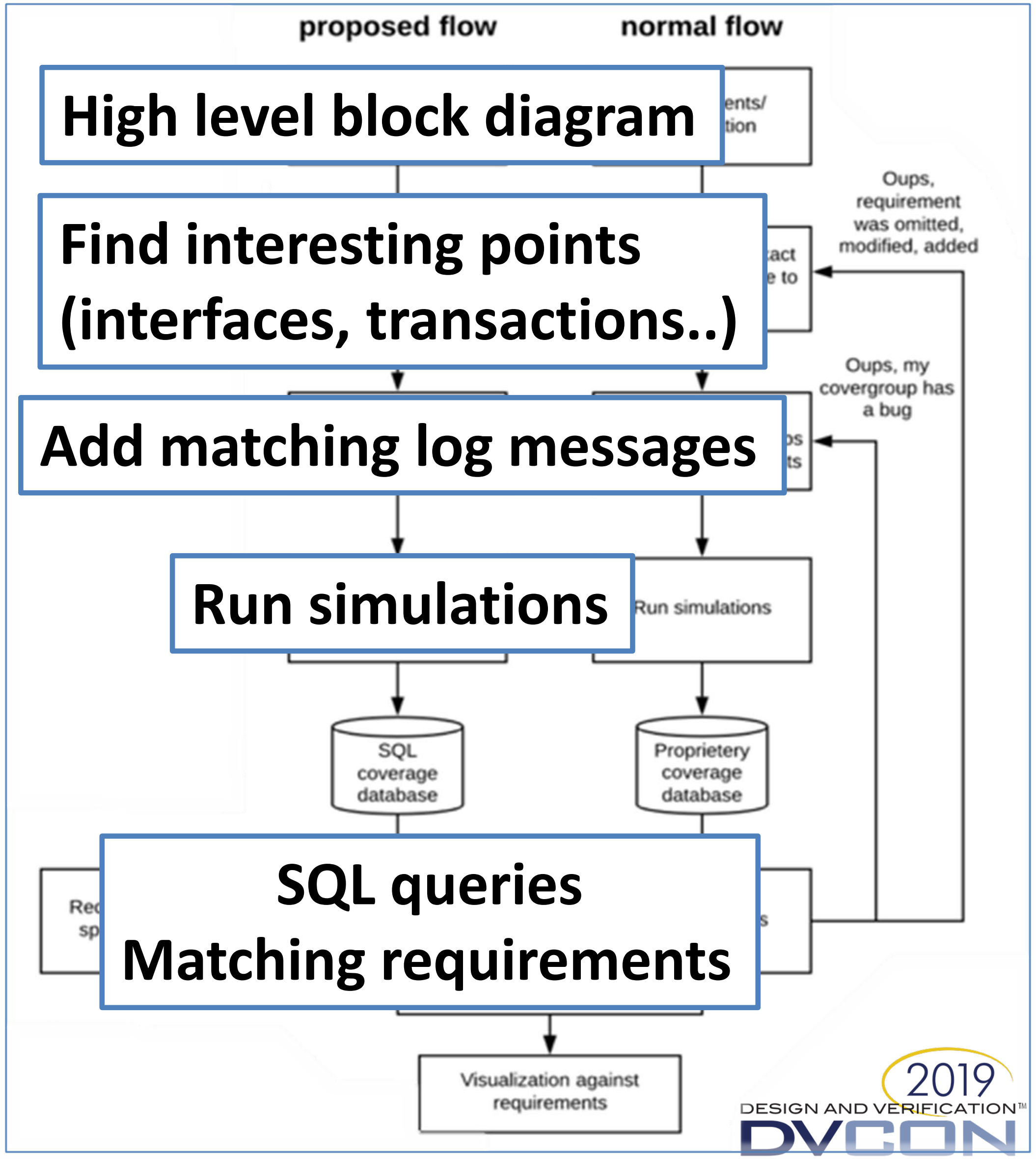
Traditional vs Proposed flow

- In a traditional flow -> right hand side,
  - starts from a list of requirements or spec,
  - thing about exact situations to cover
  - coverage model including cover groups and assertions is derived.
  - Regressions are run, and results are then visualized
- holes would require debugging, patching and rerunning



Proposed Flow

- while coding testbench come up with is a list of interesting points to watch
- add logging code into those places
- Run the regression to get a database
- At the end <u>use requirements</u>
- Look at the requirements and link them to queries



SQL as a coverage tool

- SQL can be fine-tuned, focused and extended without re-running the sim
  - High level of SQL queries enough - Many new possibilities, also few limitations
- assume that there is an already parsed transaction log file collected on an AXI interface
- placed the transactions in an SQL table called **axi_if_1**

time	rd/wr	addr	burst	len
150	RD	165377426	INCR	12
250	RD	2310710676	FIXED	13
350	WR	2328599037	FIXED	15
360	WR	2921785595	INCR	6
500	RD	1490070710	INCR	0
550	RD	3668650794	FIXED	8
1000	WR	1314868187	INCR	13
1100	RD	3114753989	FIXED	10
1110	RD	2032547025	FIXED	14
1120	WR	2834194867	INCR	4
1490	RD	4294967295	FIXED	8

name	value
RD	0
WR	1

name	value
FIXED	0
INCR	1
WRAP	2

```
typedef enum burst_type_t {FIXED = 0, INCR = 1, WRAP =2};

//…
burst_type_t burst;

covergroup axi_tr;
   burst : coverpoint burst;
endgroup
```

all distinct values in the burst type column – no WRAP type!

```
SELECT DISTINCT burst FROM axi_if_1
```

burst
INCR
FIXED

all distinct values in the burst type column – no WRAP type!

```
SELECT DISTINCT # (3)
    t.name AS expected, # (1)
    IF(axi.burst IS NOT NULL, 'TRUE', 'FALSE') AS hit #(4)
FROM burst_type t
LEFT JOIN axi_if_1 axi
    ON t.name=axi.burst #(2)
```

expected	hit
INCR	TRUE
FIXED	TRUE
WRAP	FALSE

SQL as a coverage tool 2

- On AXI common to cross burst type and direction

```
SELECT DISTINCT
    t1.name AS burst,
    t2.name AS rd_wr,
    IF(axi.burst IS NOT NULL, 'TRUE', 'FALSE') AS hit
FROM burst_type t1 CROSS JOIN rdwr_type t2
LEFT JOIN axi_if_2 axi ON
    t1.name=axi.burst AND
    t2.name=axi.rd_wr
WHERE
    t1.name <> 'INCR' OR
    t2.name <> 'RD'
```

Resulting table:

burst	direction	hit
INCR	RD	TRUE
FIXED	RD	TRUE
FIXED	WR	TRUE
INCR	WR	TRUE
WRAP	RD	FALSE
WRAP	WR	FALSE

- *All possible expected values*
- *match those expected values to the actual values,*

what is needed is a ‘LEFT JOIN’ with the AXI transactions

with matching lines that have both burst and rd/wr equal

- *ignoring one of the combinations with ‘WHERE’*
- *Find which combinations were hit*

Coverage percentage

- One of the most important part in functional coverage

Example: Coverage numbers across burst type, direction and memory segment.

```
SELECT AVG(hit)*100 AS coverage_number FROM (
    SELECT DISTINCT
        t1.name AS burst,
        t2.name AS direction,
        t3.ctr * 1000000000 AS segment,
        IF(axi.addr IS NOT NULL, 1, 0) AS hit
FROM burst_type t1
CROSS JOIN rdwr_type t2
CROSS JOIN (SELECT ctr FROM ctr_to_100 WHERE ctr < @buckets) t3
LEFT JOIN axi_if_2 axi ON
    t1.name=axi.burst AND
    t2.name=axi.rd_wr AND
    t3.ctr=floor(axi.addr/1000000000)) t4
```

Average function can be introduced

TRUE/FALSE column replaced with binary

the address range split in buckets and generated a new list of expected buckets

coverage_number
29.1666

Getting the data on the cloud

- Cloud service – any available service can be used
- Data manipulation glue code – python used
- Steps
  - Print transactions and data types into log
  - Having the logs and type information files uploaded to the cloud
  - Turn these logs in to SQL tables (using available cloud services)
  - Query the tables for coverage as described
  - As a last step visualize the tables linked to a test plan, possibly alongside other forms of coverage (legacy SV, formal, SVA).

Printing

- Only one step in verification environment – print statements
  - transactions
  - simulation points and
  - all possible enumerated data types …
- The example of one way how to do it is shown below:

```
//initialization section: print type information for the fields in our log
$display("# Transaction meta: %s, %d, %s, %d, %d, %s", $typename(tr.dir),
$size(tr.addr), $typename(tr.burst), $size(tr.len), $size(tr.id),
$typename(tr.lock));
// ...
//run section: print the interesting parst of each transaction into the log
$display("# Time: %t, dir: %s, addr: %d, burst: %s, len: %d, id: %d, lock:
%s,",$time(), tr.dir.name, tr.addr, tr.burst.name, tr.len, tr.id, tr.lock.name);
```

Additional data

- To get cross coverage including holes the type information needed
- ***$display*** statement translate into a format that can be read into a database.
- Easily done with python

```
types.json
{"enum_type_name": "axi_vip::dir_t", "enum_string": "RD", "enum_int": "0"}
{"enum_type_name": "axi_vip::dir_t", "enum_string": "WR", "enum_int": "1"}
{"enum_type_name": "axi_vip::burst_t", "enum_string": "FIXED", "enum_int": "0"}
{"enum_type_name": "axi_vip::burst_t", "enum_string": "INCR", "enum_int": "1"}
{"enum_type_name": "axi_vip::burst_t", "enum_string": "WRAP", "enum_int": "2"}
{"enum_type_name": "axi_vip::lock_t", "enum_string": "NORMAL", "enum_int": "0"}
{"enum_type_name": "axi_vip::lock_t", "enum_string": "EXCLUSIVE", "enum_int": "1"}
{"enum_type_name": "axi_vip::lock_t", "enum_string": "LOCKED", "enum_int": "2"}

columns.csv
dir,       axi_vip::dir_t,     0
addr,      int,                32
burst,     axi_vip::burst_t,   0
len,       int,                4
id,        int,                4
lock,      axi_vip::lock_t,    0
```

Upload to the cloud

- Directory structure on the cloud
  - For a single cover group
  - Sampled at the same time

```
simple_tb/
├── test1
│   └── axi_master_1
│       ├── columns
│       │   └── columns.csv
│       └── log
│           └── transactions.log
└── types_info
    └── types.json
```

SQL tables

- Cloud platforms have different services that employ SQL queries on the data
- Used example platform – service that directly creates DB and tables from files
- "json" and "csv" files are natively translated
- Log files can be translated with user defined format

SQL tables

- Main table – log
- Others: Meta data for all types, Enum type specific table

```
CREATE EXTERNAL TABLE demo.axi_if1_trans (
    `time` bigint,
    `dir` string,
    `addr` bigint,
    `burst` string,
    `len` smallint,
    `id` smallint,
    `lock` string
     )
     ROW FORMAT SERDE 'org.apache.hadoop.hive.serde2.RegexSerDe'
     WITH SERDEPROPERTIES (
         'input.regex'='# Time: *([^ ^,]*), dir: *([^ ^,]*), addr: *([^ ^,]*), 
burst: *([^ ^,]*), len: *([^ ^,]*), id: *([^ ^,]*), lock: *([^ ^,]*),'
     ) LOCATION 's3://db-name/simple_tb/test1/axi_master_1/log/'
     TBLPROPERTIES ('has_encrypted_data'='false');
```

Last step – query & visualize

- Use queries to get interesting points

Advanced example:

- interrupted exclusive read/write pairs

```
select first_tr.addr as addr, first_tr.time as read_time,  min(middle_tr.time) as
interrupted_at, min(second_tr.time) as write_time
from (
    select row_number() over () as num,
                inner1.time,inner1.addr,inner1.dir,inner1.lock
       from axi_if1_transactions inner1
       where inner1.dir = 'WR' or inner1.lock = 'EXCLUSIVE'
       order by inner1.addr, inner1.time) as first_tr,
    (
    select row_number() over () as num,
                inner1.time,inner1.addr, inner1.dir,inner1.lock
       from axi_if1_transactions inner1
       where inner1.dir = 'WR' or inner1.lock = 'EXCLUSIVE'
       order by inner1.addr, inner1.time) as second_tr,
    (
    select row_number() over () as num,
                inner1.time,inner1.addr,inner1.dir,inner1.lock
       from axi_if1_transactions inner1
       where inner1.dir = 'WR' or inner1.lock = 'EXCLUSIVE'
       order by inner1.addr, inner1.time) as middle_tr
where first_tr.addr = second_tr.addr and
      second_tr.addr = middle_tr.addr and
     first_tr.lock = 'EXCLUSIVE' and second_tr.lock = 'EXCLUSIVE' and
     first_tr.dir = 'RD' and second_tr.dir = 'WR' and middle_tr.dir = 'WR' and
     first_tr.num < middle_tr.num and middle_tr.num < second_tr.num
group by 1,2;
```

- *group the results by the time of the exclusive-read*
- *ask for the minimum on the interfering write and the exclusive-write*
- *To remove the false paths*

*order the results by **addr** and **write_time** and look for **max(read_time)***

	addr	read_time	interrupted_at	write_time
1	1490070710	0	26	181
2	1490070710	207	290	300

Conclusions

- At a high level SQL can replace almost all aspects of System Verilog coverage
- Using queries
  - dynamic and platform independent
  - Can be done long after the simulation has ended
  - Can be modified and debugged on-the-fly
  - Give the same information in a more convenient way
  - Can do much more with the data at hand

Questions?