"C" you on the faster side: Accelerating SV DPI based co-simulation

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Introduction: C Integration Support

- DPI - SystemVerilog Standard
  - An interface between SystemVerilog and a foreign programming language: C or C++
- Simple interface to C models
  - Allows SystemVerilog to call a C function just like any other native SystemVerilog function/task
  - Variables passed directly to/from C/C++
  - NO need to write PLI-like applications/wrappers
- Why DPI
  - Easy of use
  - Allows SystemVerilog to call a C function just like any other native SystemVerilog function/task
  - Direct interface provides better performance
- Support both functions and tasks

DPI: Two-way Communication

- **Import "DPI"**
  - SystemVerilog calling C/C++ functions

```
import "DPI-C" context task c_test(input int addr);

program automatic top;
  initial c_test(1000);
  initial c_test(2000);
endprogram
```

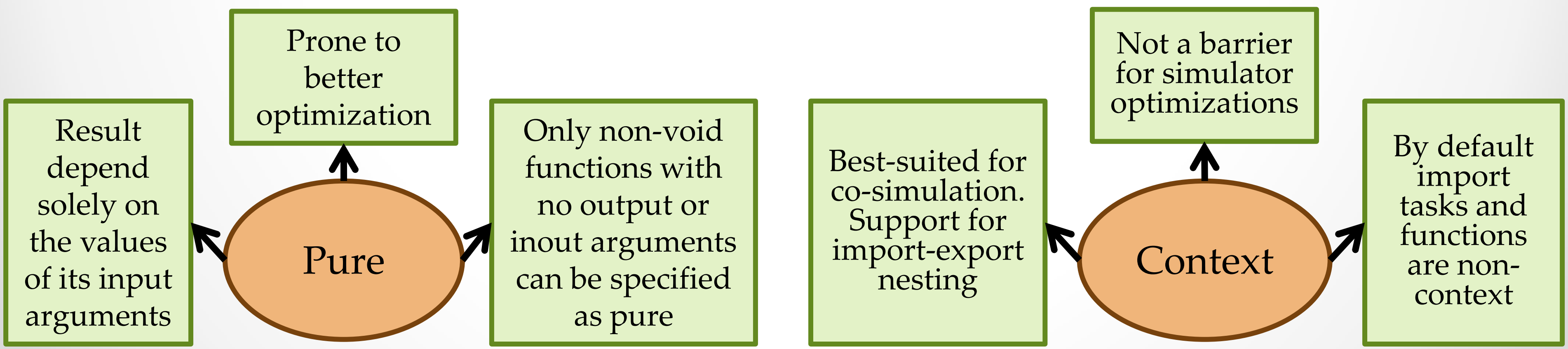
```
#include <svdpi.h>

void c_test(int addr) {
  ...
}
```

- **Export "DPI"**
  - C calls SystemVerilog functions
  - C calls SystemVerilog (blocking) tasks

```
import "DPI-C" context task c_test(int addr);
initial c_test(1000);
export "DPI-C" task apb_write;

task apb_write(input int addr, data);
  ... @(posedge ready); ...
endtask
```

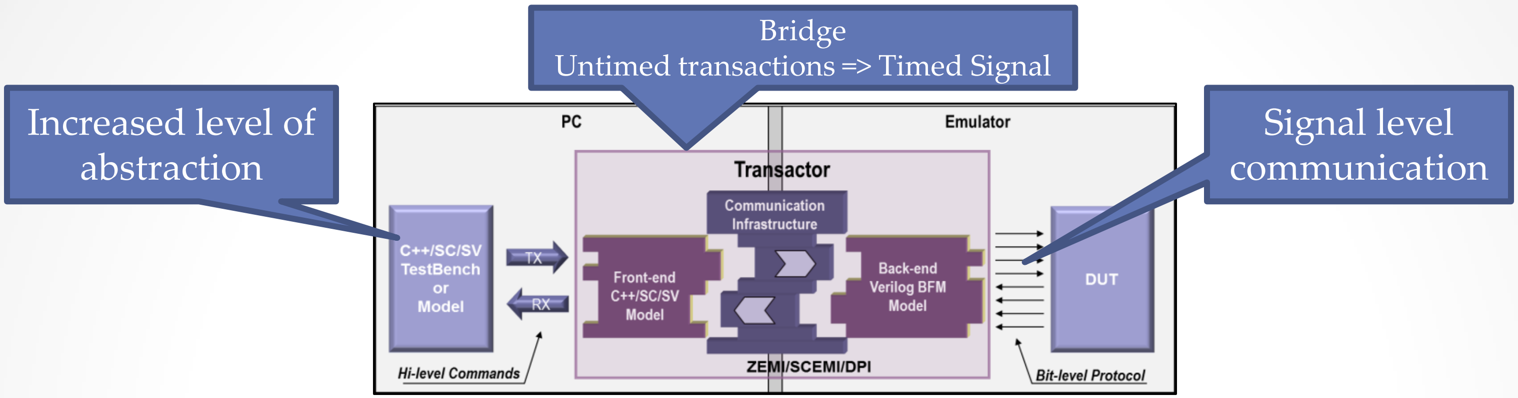
```
#include <svdpi.h>
extern void abp_write(int, int);

void c_test(int base_addr) {
  ...
  apb_write(addr, data);
  ...
}
```

DPI: Pure vs. Context Declarations

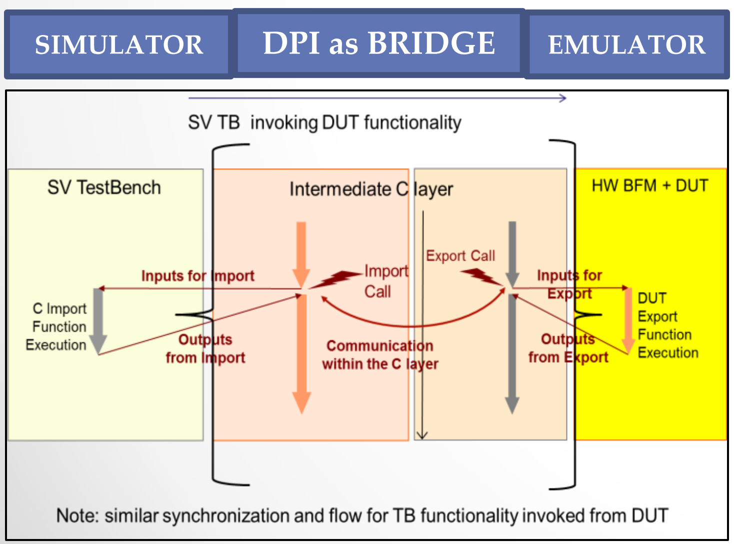


Co-simulation Using DPI :

Transactor Based Verification



Result: The speed improvement over cycle-based can be orders of magnitude faster reaching tens of MHz



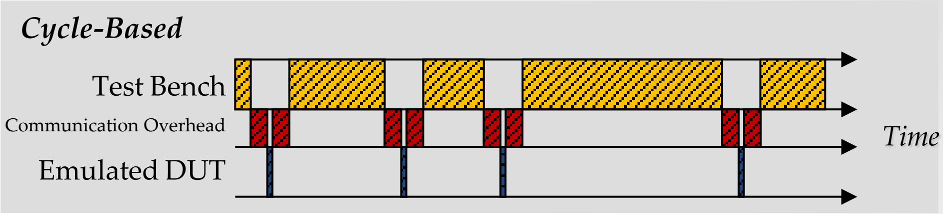
Step 1: An 'import' task/function which carries the relevant data to the hardware side.

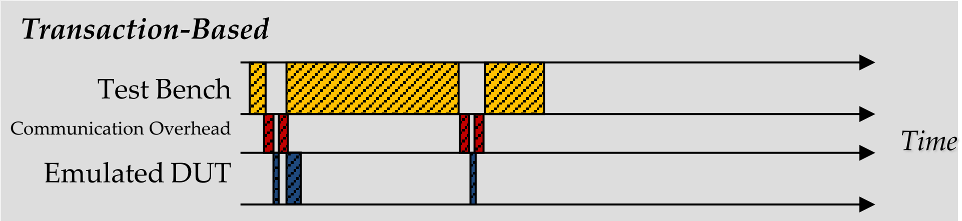
Step II: The Intermediate C layer maps HW/SW calls with the correct data types and

Step III: forwards the data and invokes the hardware time consuming method through an export task.

Achieving co-simulation performance

Testbench and DUT are synchronized on a cycle basis, and communication overhead occurs at each and every cycle





With Transaction-Based Emulation, synchronization is done only when required

Challenge: Reduce the inefficiencies in ***Communication***

- Reduced Frequency of DPI calls
- Enabling efficient communication
  - Appropriate usage of language constructs
  - Recommendations for more efficient data transfers

- Improved communication schemes
  - Offline processing
  - Leveraging Multi-threading
  - Enabling concurrency in the 'C' domain
  - Efficient File I/O

Reduced Communication Overhead

Appropriate Usage Of Language Constructs

- Declare imported functions as ‘pure’ whenever possible, to allow for more optimizations.
- Preferably use data types that map to native C-data
- Avoid usage of scalar data types (bit/reg/logic) mapped to scalar “unsigned char”, and the packed counterparts mapped to canonical form.
- The SystemVerilog-specific types, including packed types (arrays, structures, unions), which have no natural correspondence in C.

SystemVerilog	C (input)	C (out/inout)
byte	char	char*
shortint	short int	short int*
int	int	int*
longint	long int	long int*
shortreal	float	float*
real	double	double*
string	const char*	char**
string[n]	const char**	char**

SystemVerilog	C (input)	C (out/inout)
bit	svBit	svBit*
logic, reg	svLogic	svLogic*
bit[N:0]	const svBitVecVal*	svBitVecVal*
reg[N:0] logic[N:0]	const svLogicVecVal*	svLogicVecVal*
Open array[ ] (import only)	const svOpenArrayHandle	svOpenArrayHandle
chandle	const void*	void*

Reduced Communication Overhead

Reduced Number of Argument in DPI calls

- Each argument should be declared as narrow as possible
  - for example, never use the 'int' data type if the argument can only be 0/1.
- Combine them and prune argument lists to reduce the amount of data transferred from the simulator

```
import "DPI-C" context function void compare_values
   (int unsigned  mem_idx, int unsigned CAL_VAL, int unsigned  ADDRESS);
```

```
import "DPI-C" context function void compare_values
    (bit[7:0] mem_idx, bit[15:0] CAL_VAL, bit[31:0] ADDRESS);
```

```
`define VA8_T     byte unsigned     // bit[7:0]
`define VAL_T     shortint unsigned // bit[15:0]
`define ADD_T     int unsigned      // bit[31:0]
```

```
import "DPI-C" context function void compare_values
    (`VA8_T mem_idx, `VAL_T CAL_VAL, `ADD_T ADDRESS);
```

Reduced Communication Overhead

Reduced Frequency of DPI calls

- If DPI calls are very frequent,
  - Each DPI call results in a transfer of at least a n-bit packet header. Additional n-bit words are added to the packet to convey argument values.
  - When passing a limited number of constants, try to create multiple versions of DPI functions to eliminate the need for constants.

```
import "DPI-C" context function void compare_values
    (`VA8_T mem_idx, `VAL_T CAL_VAL, `ADD_T ADDRESS);
```

```
import "DPI-C" function void compare_values_EDGE
    (`ADD_T add, `VAL_T val);
```

Reduced Communication Overhead

Reduced Frequency of DPI calls

- Reduction of redundant calls, for example,
  - if both f() and g() are functions that take a one bit wide argument each (SV 'bit' data type), then "f(a); f(b); g(c); g(d);" causes a transfer of 4*2(n-bit) words. One way to minimize the total amount of words transferred is to combine calls. In the above example, by creating a new wrapper function ffgg(bit a, bit b, bit c, bit d), we can reduce the total transfer size from 4*2(n-bit) words to 2(n-bit).

```
import "DPI-C" context function void compare_values
   (`VA8_T mem_idx, `VAL_T CAL_VAL, `ADD_T ADDRESS);
```

```
import "DPI-C" context function void compare_values
   (`VA8_T mem_idx, `VAL_T CAL_VAL, `ADD_T ADDRESS);
```

Comparison of content for two memories
@ Same event and same address
with different values

```
import "DPI-C" function void compare_values_HV
         (`ADD_T add, `VAL_T val_0, `VAL_T val_1);
```

Specialized function
-> Infer mem_idx implicitly
-> Reduced arguments
-> Reduced number of call

Reduced Communication Overhead

Tips for efficient data transfers

To enhance data transfers to the host PC (System Verilog),

- Avoid unused bits by using the narrowest data type possible
- Avoid logic vector (4-state) arguments and unpacked structures
- Use arguments whose width is less than or equal to 32 bits
- Concatenate large numbers of short vectors in Verilog and unpack them on the C++ side. This will ensure more data transfer with less communication overhead.
- Bit-vectors aligned with 32-bit or multiple of 32-bits boundaries yields greater performance. So does the use of 64 bit wide integers as they are natively mapped as longint on C-side.

On the C-front:

- If the memory/array is 16-bit/8-bit wide then use appropriate data type for building C-side arrays. For example, use byte to map the 8-bit wide vectors, shortint for 16-bit wide vectors etc.
  - Using wider elements than needed is a bad idea for two reasons:
    - RAM usage goes up, and
    - CPU cache may become clogged with junk.

Communication schemes

- **Offline processing**
  - Parameters that are passed via the DPI call to the 'C' side are off-loaded for offline process,
    - by assigning these to some global data structures defined in the imported domain and the main function resumes the execution of the functionality further.

- **Leveraging Multi-threading**

Thread Declaration

```
void* rc_lnk_trg(void* arg) {
  Pcie foo = *((Pcie*)(arg));
  foo.rc->runBFM(PCIE::RunUntilTrainingDone);
  return (NULL);
}

void* ep_lnk_trg(void* arg) {
  Pcie foo = *((Pcie*)(arg));
  foo.ep->runBFM(PCIE::RunUntilTrainingDone);
  return (NULL);
}
```

Thread Creation

```
int XactorConfigure(int is_root, int inst_n) {
  pthread_t _link;
  if(is_root == 1) {
    pthread_create(&_link, NULL, &rc_lnk_trg, &_Pcie[inst_n]);
  }
  else {
    pthread_create(&_link, NULL, &ep_lnk_trg, &_Pcie[inst_n]);
  }
  pthread_join(_link, NULL);
  return (1);
}
```

Import Declaration

```
import "DPI-C" context task XactorConfigure(int is_root, int inst_n);
```

Import Call

```
task configure_phase(uvm_phase phase);
  phase.raise_objection(this);
  super.configure_phase(phase);
  fork
    XactorConfigure(cfg.is_root, inst_n);
  join
  phase.drop_objection(this);
endtask
```

Reduced Communication Overhead

Communication schemes

- **Efficient File Operations**
  - <u>Original Case:</u> In this example we have 56 variable sized memories that needs to be loaded using the HEX dump files

```
int* PAT_MEM_AA;// [(H_PIXEL   )];
int* PAT_MEM_AB;// [(H_PIXEL   )];
….
int* PAT_MEM_BA;// [(T_PIXEL*3)];
int* PAT_MEM_BB;// [(T_PIXEL*3)];
….
int* PAT_MEM_CA;// [(T_PIXEL   )];
int* PAT_MEM_CB;// [(T_PIXEL   )];
….
```

HEX Files

SERIAL LOADING

```
read_file("AA_Info.hex", PAT_MEM_AA);
read_file("AB_Info.hex", PAT_MEM_AB);
read_file ("BA_Info.hex", PAT_MEM_BA);
read_file ("BB_Info.hex" , PAT_MEM_BB);
read_file ("CA_Info.hex", PAT_MEM_CA);
read_file ("CB_Info.hex" , PAT_MEM_CB);
```

Loading Time

BIN Files

PARALLEL LOADING

```
pthread_t f[3];
printf("Loading started...\n");
  pthread_create(&f[0],  NULL, &load_file1,  NULL);
  pthread_create(&f[1],  NULL, &load_file2,  NULL);
  pthread_create(&f[2],  NULL, &load_file3,  NULL);

  pthread_join(f[0],  NULL);
  pthread_join(f[1],  NULL);
  pthread_join(f[2],  NULL);
printf("Loading done...\n");

void* load_file1(void*) {
  read_file("AA_Info.hex", PAT_MEM_AA);
  read_file("AB_Info.hex", PAT_MEM_AB);
}
void* load_file2(void*) {
  read_file ("BA_Info.hex", PAT_MEM_BA);
  read_file ("BB_Info.hex" , PAT_MEM_BB);
}
void* load_file3(void*) {
  read_file ("CA_Info.hex", PAT_MEM_CA);
  read_file ("CB_Info.hex" , PAT_MEM_CB);
}
```

Using efficient File IO

```
void read_file(char* file_path, int* buffer) {
  printf("The file loading from path:%s\n",
file_path);

  ifstream file(file_path);
  int value = 0;
  while(file >> hex >> buffer[value++]) { }
  if(file.eof()){value--;}
  file.close();
}
```

Results & Summary

Improvements observed in simulation performance and memory overhead for the following setups:

- A UVM frontend leveraging SV DPI to communicate with a Synthesizable PCIe transactor
- DPI based scoreboard and reference for a video decoder block

Changes Done	Percentage Improvement
Improvement using less number of DPI calls : 100 secs for 35 DPI calls got reduced to 30 secs for 20	3.33X
Using efficient file IO operations : usage of standard file streaming leads to a reduction from 90 secs to 15 secs	6X
Loading binary files against hex files	5X
Introducing threading : in file loading operation – time improved from 50 secs to 10 secs	5X
Usage of correct and compact and native C data types	1.5X
Offline processing on the C-side	2X