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The Verilog PLI Is Dead (maybe)...
Long Live The SystemVerilog DPI!

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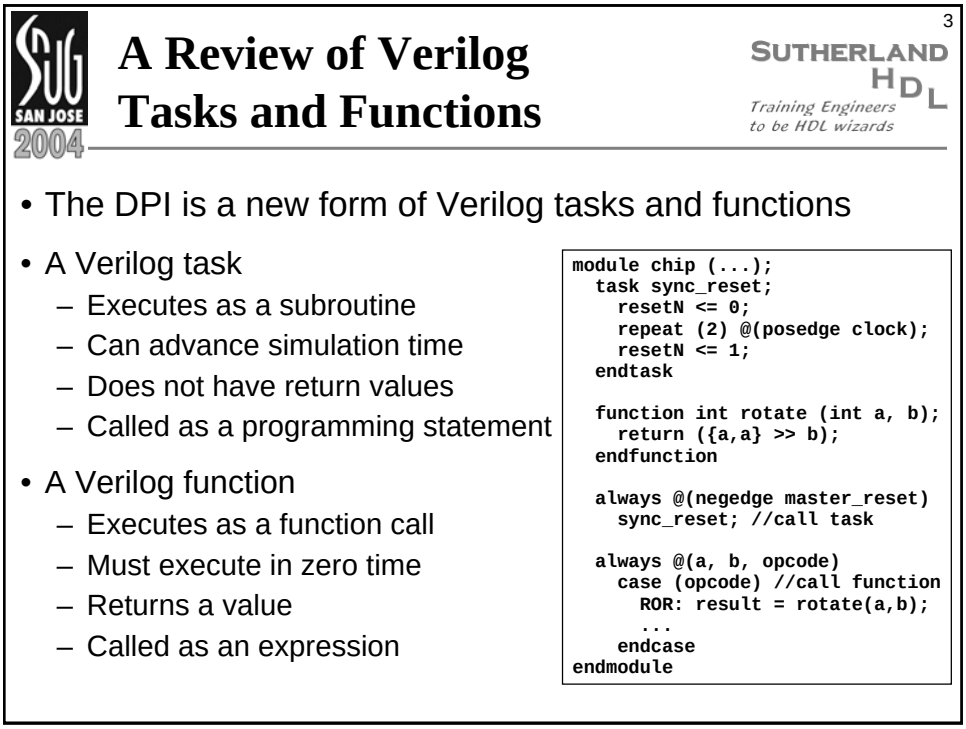
Objectives

- Introduce the SystemVerilog DPI
- Verilog PLI strengths and weaknesses
- Show how the SystemVerilog DPI works
- Compare and contrast PLI and DPI
- Decide if the PLI is finally dead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A Review of Verilog Tasks and Functions
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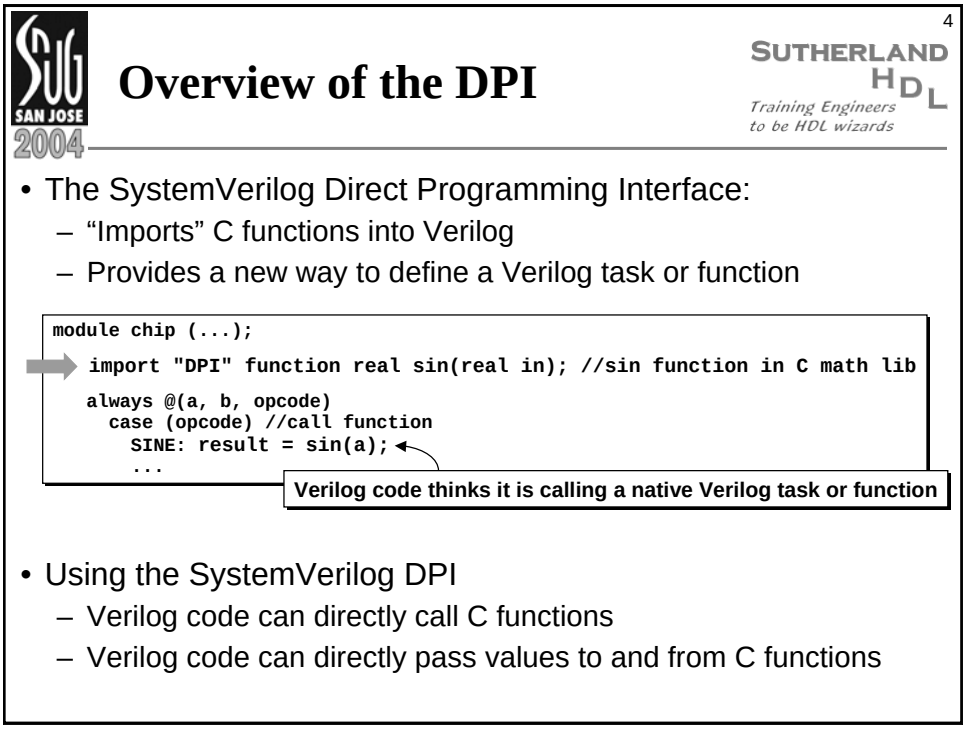
• The DPI is a new form of Verilog tasks and functions
• A Verilog task
– Executes as a subroutine
– Can advance simulation time
– Does not have return values
– Called as a programming statement
• A Verilog function
– Executes as a function call
– Must execute in zero time
– Returns a value
– Called as an expression
module chip (...);
task sync_reset;
resetN <= 0;
repeat (2) @(posedge clock);
resetN <= 1;
endtask
function int rotate (int a, b);
return ({a,a} >> b);
endfunction
always @(negedge master_reset)
sync_reset; //call task
always @(a, b, opcode)
case (opcode) //call function
ROR: result = rotate(a,b);
...
endcase
endmodule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Overview of the DPI
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• The SystemVerilog Direct Programming Interface:
– "Imports" C functions into Verilog
– Provides a new way to define a Verilog task or function
module chip (...);
import "DPI" function real sin(real in); //sin function in C math lib
always @(a, b, opcode)
case (opcode) //call function
SINE: result = sin(a);
...
Verilog code thinks it is calling a native Verilog task or function
• Using the SystemVerilog DPI
– Verilog code can directly call C functions
– Verilog code can directly pass values to and from C functions

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What's Next

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- ✓ Introduce the SystemVerilog DPI
- ❑ Verilog PLI strengths and weaknesses
- ❑ Show how the SystemVerilog DPI works
- ❑ Compare and contrast PLI and DPI
- ❑ Decide if the PLI is finally dead

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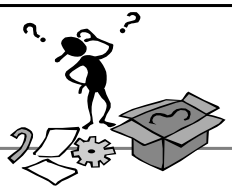
Verilog PLI Details



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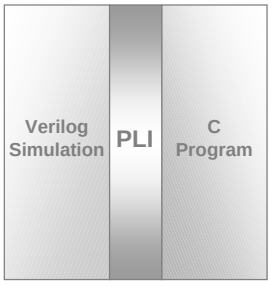
- Need to know how PLI works in order to compare to DPI...
- The Verilog PLI is a *simulation interface*
  - Reads/modifies simulation data structures
  - Does not read Verilog source code
  - Does not work with synthesis compilers or other tools



The PLI is a protecting layer between *user programs* and *simulation data structure*

- *Indirect access* through PLI libraries
  - C program cannot directly read or modify the simulation data
  - Protects the simulator from bad C programs
  - Protects C programs from bad Verilog code

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Overview of the Verilog PLI

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- The PLI allows users to extend Verilog by creating "user-defined system tasks and system functions"
  - Must begin with a dollar sign ($)
  - Called the same as with Verilog tasks and functions

```
always @(a, b, opcode)
  case (opcode) //call function
    SINE: result = $sine(a); // call a PLI application
```

- A system task/function invokes a "calltf routine"
  - A user-defined C function associated with the task/function name
    - Can indirectly read system task/function argument values
    - Can indirectly return values back to simulation
- Defining system task/function names and calltf routines is:
  - Complex
  - Varies from one simulator to another

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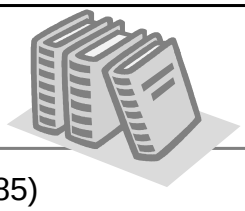
PLI Libraries



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- TF library (introduced in 1985)
  - Provides access to system task/function arguments
  - Provides synchronization to simulation time and events
- ACC library (introduced in 1989)
  - Extends TF library to access to design structure
  - Created to enable ASIC delay and power calculation
- VPI library (introduced in 1995)
  - Superset of TF and ACC libraries
  - Adds access to behavioral and RTL models
- NOTE! The IEEE is considering deprecating (removing) the TF and ACC libraries from the 1364 standard
  - Only the VPI library supports the new Verilog-2001 features
  - Only the VPI library will support SystemVerilog enhancements

The Power of the PLI

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- Supports system task/function arguments of any type
  - Data types, instance names, scopes, null arguments, etc.
  - Allows a variable number of task/function arguments
- Safe conversion of Verilog values to/from C values
  - Automatically converts any Verilog type to any C type
- Can find any modeling object anywhere in the data structure
- Can synchronize to simulation time
  - After blocking assignments, after nonblocking assignments, after all events, at future simulation times, etc.
- Can synchronize to any type of simulation event
  - Start, stop (breakpoints), finish, save, restart, logic value changes, strength level changes, RTL statement execution, etc.
- Supports multiple instances of system tasks/functions

The Disadvantages of the Verilog PLI

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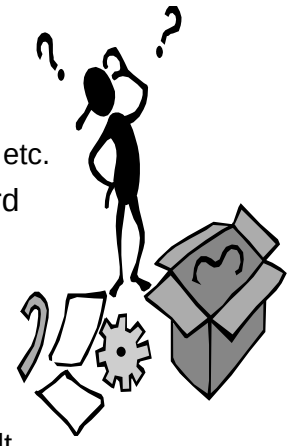

- Writing PLI applications is difficult to do
  - Must learn weird PLI terminology
  - Must learn what's in the PLI libraries
  - Must create checktf routines, calltf routines, etc.
- Linking PLI applications to simulators is hard
  - Multiple steps involved
    - Different for every simulator
  - Who does the linking...
    - The design engineer?
    - A CAE tool administrator?
  - Managing multiple PLI applications is difficult
- PLI code is seldom binary compatible
  - Must re-compile for every simulator

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What's Next

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- ✓ Introduce the SystemVerilog DPI
- ✓ Verilog PLI strengths and weaknesses
- ❑ Show how the SystemVerilog DPI works
- ❑ Compare and contrast PLI and DPI
- ❑ Decide if the PLI is finally dead

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The DPI Makes Calling C Easy!

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- The Direct Programming Interface makes it very simple for Verilog code to call C functions

```
module chip (...);
   import "DPI" function real sin(real in); //sin function in C math lib
   always @(a, b, opcode)
     case (opcode) //call function
       SINE: result = sin(a);
       ...
```

Verilog code directly calls the C function

- Can directly call C functions from Verilog
  - Do not need to define complex PLI system tasks/functions
- Can directly pass values to and from C functions
  - Do not need the complex PLI libraries to read/write values

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A Closer Look at the SystemVerilog DPI

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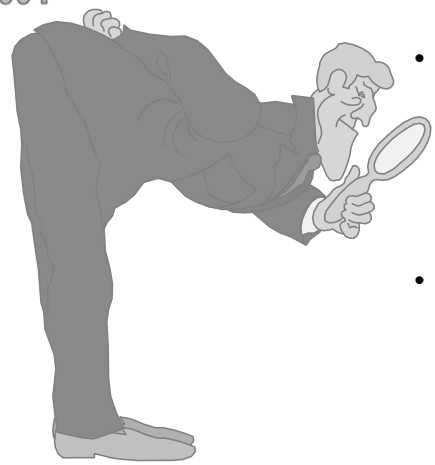

- The Direct Programming Interface originates from:
  - The Synopsys VCS DirectC interface
  - The Co-Design Cblend interface (now owned by Synopsys)
- The Accellera standards committee
  - Merged the features of each donation
  - Added more functionality
  - Ensured full compatibility with the IEEE 1364 Verilog standard
  - Added rules for binary compatibility between simulators

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More on DPI Import Declarations

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```
module chip (...);
  import "DPI" function real sin(real in); //sin function in C math lib
```

- Import declarations can be anywhere a function can be defined
  - Within a Verilog module
  - Within a SystemVerilog interface
  - Within a SystemVerilog package
  - Within a SystemVerilog “compilation unit”
- Import declarations must have a prototype of the arguments
  - Must exactly match the number of arguments in the C function
  - Must specify compatible data types (details on a later slide)
- The same C function can be imported in multiple locations
  - Each prototype must be exactly the same
  - A better method is to define one import in a package

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Imported Function Arguments

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- C functions can be imported as a Verilog task or function

```
import "DPI" function real sin(real in); //sin function in C math lib

import "DPI" task file_write(input string data, output reg status);
```

- The C function arguments can be imported as input, output or inout (bidirectional)
  - Arguments are assumed to be inputs unless declared otherwise

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Task/Function Argument Data Types

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- The import declaration ***must*** specify SystemVerilog data types that are compatible with the actual C function data types

	SystemVerilog Data Type	C Data Type
SystemVerilog types that map directly to C types	byte	char
	shortint	short int
	int	int (32-bit)
	longint	long long
	real	double
	shortreal	float
	chandle	void*
	string	char*
	enum (using default int type)	int
SystemVerilog types that require extra coding in C	bit (2-state type, any vector size)	abstract array of int types
	logic (4-state type, any vector size)	abstract aval/bval pair arrays (like PLI)
	packed array	abstract representation
	unpacked array	abstract representation

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Using More Complex Data Types

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- Structures and unions
  - Can be passed to equivalent C structures and unions
  - Must use compatible types within the structure or union
- Arrays (unpacked)
  - Can be passed to equivalent C arrays
  - Must use compatible types within the structure or union
  - The array indexing might change (C must always starts with 0)
- Vectors of 2-state data types (packed arrays of bit type)
  - Must be converted to integer arrays in C
  - Requires lots of extra coding in C
- Verilog 4-state data types (packed arrays of reg, wire, etc.)
  - Uses the Verilog PLI aval/bval encoding
  - Requires lots of extra coding in C

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Compatibility Warning!

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Warning! Warning!

- It is the user's responsibility to correctly declare compatible data types in an import statement
  - Improper declarations can lead to unpredictable run-time behavior
  - The DPI does not check for type compatibility
  - The DPI does not provide a way to check and adjust for the data types on the Verilog side (the PLI can do this)

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DPI Function Return Values

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- A C function return value must be compatible with the basic SystemVerilog data types

Imported Return Type	C Function Return Type
byte	char
shortint	short int
int	int (32-bit)
longint	long long
real	double
shortreal	float
chandle	void*

Imported functions cannot return 1-bit values, vectors, structures, unions, or enumerated types

Warning!

  - It is the user's responsibility to correctly declare an import statement that matches the C function return value
    - Incorrect import declarations can lead to unexpected behavior

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Pure, Context and Generic C Functions

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- A pure function result depends solely on the function inputs

```
import "DPI" pure function real sin(real, in);
```

  - Must have a return value; cannot have output or inout arguments
  - Cannot call any other functions or use static or global variables
  - Can be highly optimized for simulation performance **Advantage!**
- A context function is aware of the Verilog scope in which it is imported

```
import "DPI" context task print(input int file_id, input bit [127:0] data);
```

  - Can be a void function, and can have output and inout arguments
  - Can call functions from C libraries (for file I/O, etc.)
  - Can call many of the functions in the PLI libraries (more on this later)
- A generic function is one that is not declared as pure or context
  - Can be a void function, and can have output and inout arguments
  - Can call other C functions
  - Cannot call most functions in the PLI libraries

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Declaration Warning!

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You must do this right!

- It is the user's responsibility to correctly declare pure and context functions
  - The DPI does not check for proper declarations
  - Improper declarations can lead to unpredictable simulation behavior
  - Improper declarations can lead to software crashes

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Exporting Verilog Tasks and Functions

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- Verilog tasks and function can be exported to C
  - Exporting allows C code to call Verilog code
    - C thinks it is calling a native C function
    - C functions can synchronize to Verilog time by calling a Verilog task with time controls

```
module chip (...);
  task sync_reset(inout resetN);
    resetN <= 0;
    repeat (2) @(posedge clock);
    resetN <= 1;
  endtask

  export "DPI" sync_reset;
  ...
endmodule
```

```
function void C_model()
{
  ...
  sync_reset(rst); // call Verilog task
  ...
}
```

Export declarations do not have argument prototypes

- C calling Verilog tasks and functions is unique to the DPI!
  - There is no equivalent in the PLI

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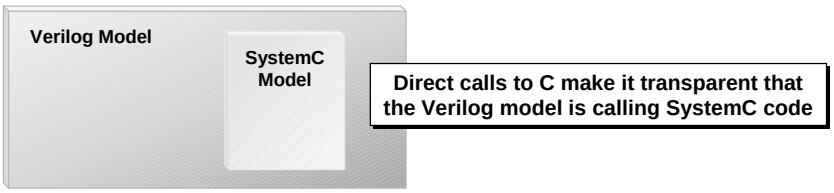
Using the DPI with SystemC

- The DPI can be used to interface SystemC models with Verilog models



  - Verilog code can directly call an imported C function that connects to the SystemC model
  - Values can be directly passed to and from the SystemC model
- Using the DPI to interface Verilog with SystemC
  - Eliminates the need for a complex PLI interface
  - Eliminates the need for proprietary, non-portable interfaces

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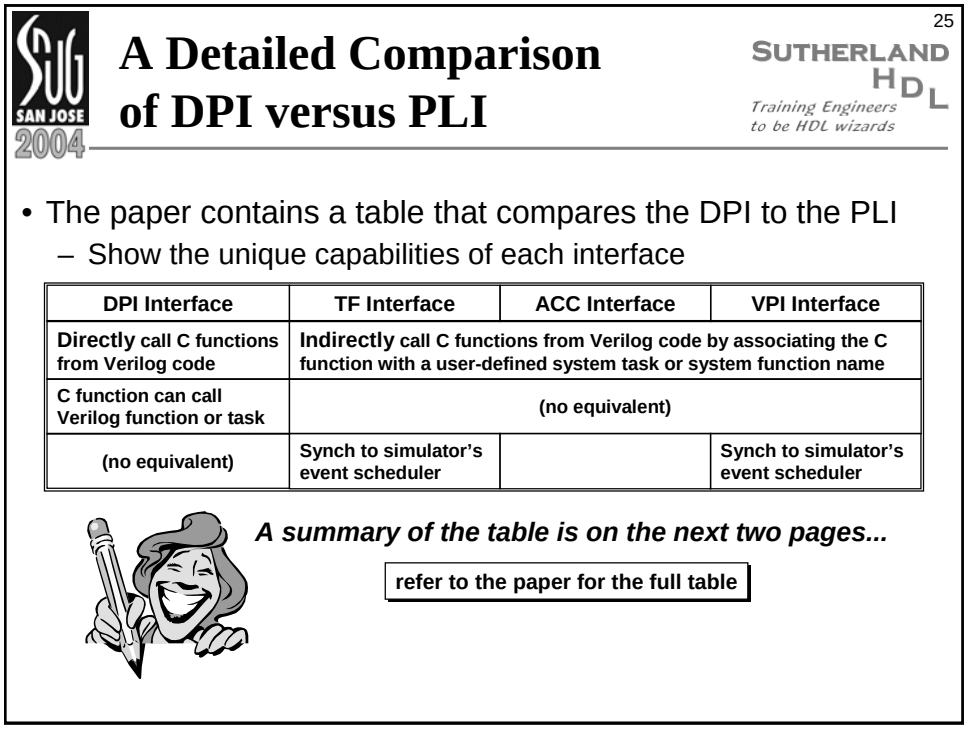
What's Next

- ✓ Introduce the SystemVerilog DPI
- ✓ Verilog PLI strengths and weaknesses
- ✓ Show how the SystemVerilog DPI works
- ❑ Compare and contrast PLI and DPI
- ❑ Decide if the PLI is finally dead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A Detailed Comparison of DPI versus PLI
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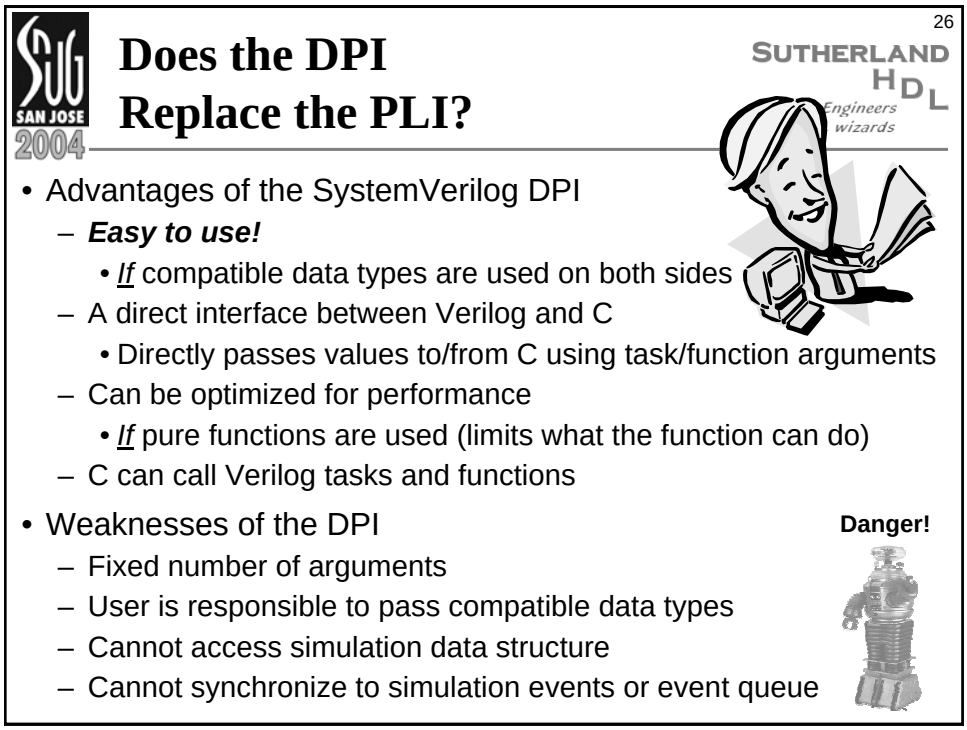
• The paper contains a table that compares the DPI to the PLI
– Show the unique capabilities of each interface
DPI Interface | TF Interface | ACC Interface | VPI Interface
Directly call C functions from Verilog code | Indirectly call C functions from Verilog code by associating the C function with a user-defined system task or system function name
C function can call Verilog function or task | (no equivalent)
(no equivalent) | Synch to simulator's event scheduler | | Synch to simulator's event scheduler
A summary of the table is on the next two pages...
refer to the paper for the full table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Does the DPI Replace the PLI?
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Engineers wizards
• Advantages of the SystemVerilog DPI
– Easy to use!
• If compatible data types are used on both sides
– A direct interface between Verilog and C
• Directly passes values to/from C using task/function arguments
– Can be optimized for performance
• If pure functions are used (limits what the function can do)
– C can call Verilog tasks and functions
• Weaknesses of the DPI
– Fixed number of arguments
– User is responsible to pass compatible data types
– Cannot access simulation data structure
– Cannot synchronize to simulation events or event queue
Danger!

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Does the DPI Replace the PLI?

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- Advantages of the Verilog PLI
  - Allows access to entire simulation data structure
    - Find any Verilog object, anywhere in the design
  - Can synchronize to simulation
    - Synch to time (before or after blocking assignments, ...)
    - Synch to value changes, breakpoints, finish, ...
  - Provides an indirect access between Verilog and C
    - Protects simulation data structure from user C code
    - Automatically converts values between Verilog and C types
- Disadvantages of the Verilog PLI
  - Difficult to learn — even simple things are hard
  - Not binary compatible — different for every simulator
  - Can slow down simulator performance (significantly)

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Using the DPI to Simplify the PLI

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- DPI capabilities can be extended by using the PLI libraries
  - A DPI context function can call many of the PLI library functions
    - Eliminates creating a system task/function name (e.g. $sine)
    - Eliminates the complex PLI binding mechanism
- NOTE: The DPI context is not the same as the PLI context
  - DPI context is the scope in which the import declaration occurs
    - Matches the behavior of native Verilog task and functions
  - PLI context is the scope in which a system task is called
  - Context functions cannot fully utilize the PLI libraries
    - Cannot use PLI checktf and misctf routines
    - Cannot access all objects in the simulation data structure

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What's Next

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- ✓ Introduce the SystemVerilog DPI
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- ❑ Decide if the PLI is finally dead

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Conclusion

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- The Verilog PLI and the SystemVerilog DPI are both needed
- Use the DPI to
  - Directly call C functions that do not need to access the simulation data structure
  - Directly call PLI applications that only need limited access to the simulation data structure
  - Interface to C and SystemC models
- Use the PLI to
  - Access any object anywhere in the simulation data structure
  - Synchronize to the simulation event queue
    - Blocking assignments, nonblocking assignments, etc.
  - Synchronize to simulation events
    - Simulation start, stop, finish, save, restart, reset, etc.

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Is the PLI Dead?

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- We cannot chant:

  "The Verilog PLI is dead...long live the SystemVerilog DPI"

  – The DPI is great, but...
  – The PLI has many capabilities not in the DPI

- The correct chant is:

  "The PLI TF/ACC libraries are dead... long live the PLI VPI and the SystemVerilog DPI, together!"

  – The DPI greatly simplifies many applications
  – The VPI replaces the old TF and ACC libraries

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Questions?

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Supplemental: About the Author

- Involved with Verilog since 1988
- Considered a Verilog PLI expert
  - Wrote that 800 page book on the PLI
- Member of IEEE 1364 standards group since beginning
  - Co-chair of the Verilog PLI task force
  - Editor of the PLI sections of the standard
- Member of Accellera SystemVerilog standards group
  - Editor of the SystemVerilog standard
- Develops and presents expert-level Verilog, PLI and SystemVerilog training courses

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Supplemental: PLI Standards

- OVI (now Accellera) PLI 1.0 (1990)
  - Standardized the original TF and ACC libraries
- OVI PLI 2.0 (1993)
  - Intended to replace PLI 1.0
  - Not backward compatible, so never implemented in simulators
- IEEE 1364-1995
  - Standardized PLI 1.0 as TF and ACC libraries
  - Rewrite of PLI 2.0 to be backward compatible, called VPI library
- Accellera SystemVerilog 3.1 (2003)
  - Adds the Direct Programming Interface (DPI) to Verilog
- Accellera SystemVerilog 3.1a (projected for April 2004)
  - Extends VPI library to support all SystemVerilog constructs
- IEEE 1354-2005 (2006 ?) [projected date]
  - Will include SystemVerilog DPI along with many VPI extensions

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Supplemental: SystemVerilog Features

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SystemVerilog

3.1a
- assertions
- test program blocks
- clocking domains
- process control
- mailboxes
- semaphores
- constrained random values
- direct C function calls

3.0
- interfaces
- nested hierarchy
- unrestricted ports
- automatic port connect
- enhanced literals
- time values and units
- specialized procedures
- packages
- 2-state modeling
- packed arrays
- array assignments
- queues
- unique/priority case/if
- compilation unit space

from C / C++
- classes
- inheritance
- strings
- dynamic arrays
- associative arrays
- references
- int
- shortint
- longint
- byte
- shortreal
- void
- alias
- globals
- enum
- typedef
- structures
- unions
- casting
- const
- break
- continue
- return
- do–while
- ++ -- += -= *= /=
- >>= <<= >>>= <<<=
- &= |= ^= %=

Verilog-2001
- ANSI C style ports
- generate
- localparam
- constant functions
- standard file I/O
- $value$plusargs
- `ifndef `elsif `line
- @*
- (* attributes *)
- configurations
- memory part selects
- variable part select
- multi dimensional arrays
- signed types
- automatic
- ** (power operator)

Verilog-1995
- modules
- parameters
- function/tasks
- always @
- assign
- $finish $fopen $fclose
- $display $write
- $monitor
- `define `ifdef `else
- `include `timescale
- initial
- disable
- events
- wait # @
- fork–join
- wire reg
- integer real
- time
- packed arrays
- 2D memory
- begin–end
- while
- for forever
- if–else
- repeat
- + = * /
- %
- >> <<

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Supplemental: Import Function Arguments

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- C functions can be imported as a Verilog task or function

```
import "DPI" function real sin(real in); //sin function in C math lib

import "DPI" task file_write(input string data, output reg status);
```

- The C function arguments can be imported as input, output or inout (bidirectional)
  - Inputs behave as if copied into the C function when it is called
    - The C function should not modify input arguments
  - Outputs behave as if copied into Verilog when the function returns
  - Inouts behave as if copied in at call, and copied out at return
  - Arguments are assumed to be inputs unless declared otherwise

The "copying" values in and out of C functions describes the behavior. Software tools can implement this behavior in many ways (using pointers, etc.)