Functional Coverage
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Agenda

- Definitions and features
- Coverage definition
  - Coverage group
  - Coverage point
    - Values and Transitions
    - User defined bins
  - Cross coverage
    - Cross product selection and exclusion
- Coverage options
- Procedural control and access to coverage

What is Functional coverage

- Measure of how much of the design specification has been exercised
  - % test plan features
- User-specified
  - Not automatically inferred from the design
- Based on design specification
  - Captures intent
  - Independent of design code or structure

Functional coverage features

- Coverage of variables and expressions
  - Cross coverage
- Automatic and user-defined coverage bins
  - Values, transitions, or cross products
- Filtering conditions at multiple levels
- Flexible coverage sampling
  - Events, Sequences, Procedural
- Directives to control and query coverage

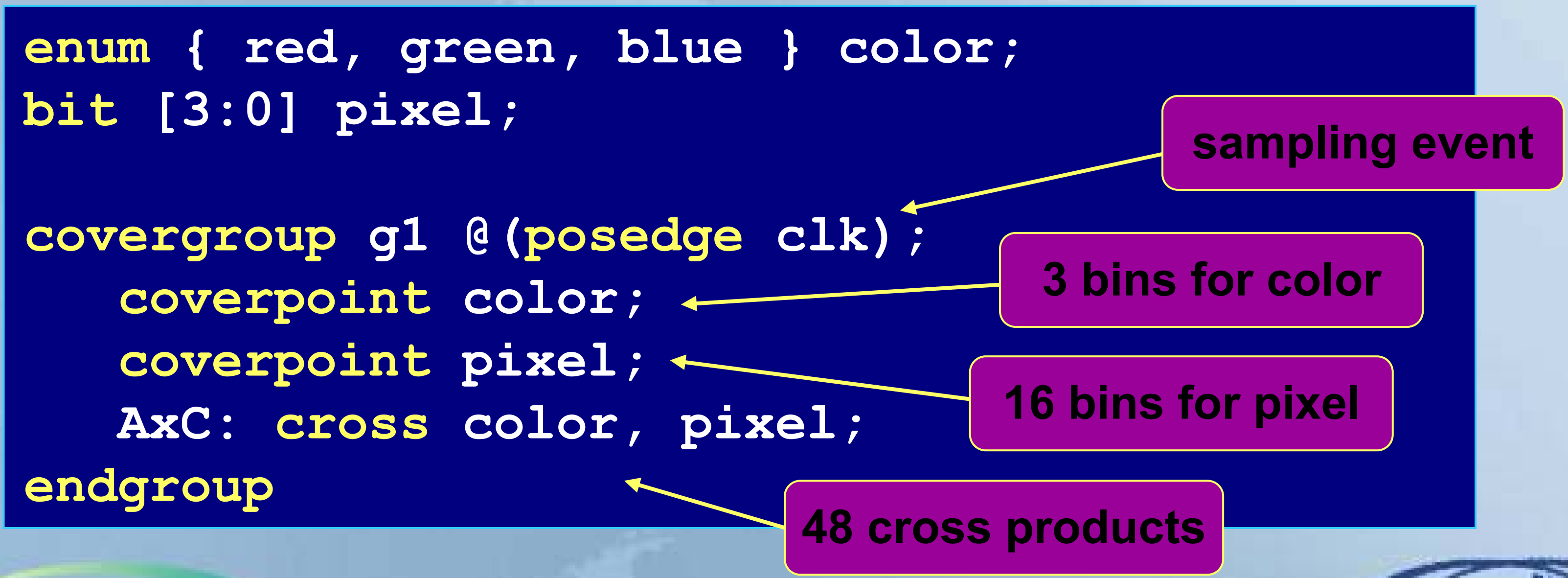
Coverage model : covergroup

New container **covergroup** : coverage model

- Coverage points
  - variables
  - expressions
  - transitions
- Cross coverage
- Sampling expression : clocking event
- Filtering expressions
- Specify once (like class), use many times
  - Cumulative or per-instance coverage

Declaration of a covergroup

```
covergroup identifier [ ( argument_list ) ]
  [ clocking_event ] ;
      { coverage_spec_or_option ;  }
endgroup [ : identifier ]
```



```
enum { red, green, blue } color;
bit [3:0] pixel;

covergroup g1 @(posedge clk);
   coverpoint color;
   coverpoint pixel;
   AxC: cross color, pixel;
endgroup
```

sampling event

3 bins for color

16 bins for pixel

48 cross products

Coverage sampling event

Sampling can be

- Any event expression - edge, variable
- End-point of a sequence
- Event can be omitted
  - Procedural sampling under user control

```
covergroup cg1 @(posedge clk);
    ...
endgroup

sequence s @(posedge clk)req ##[1:$] grant;endsequence

covergroup cg21 @(s);
    ...
endgroup
```

sampling event

sampling sequence

Defining Coverage Points

[label :] **coverpoint** expression [**iff (**expression**)**]
{ bins_or_options }

Specifies expression (or variable) to sample

- Expression is sampled and accounted in bin(s)
- Number of values/bins can be controlled
  - bins specification
- Optionally filtering expression - **iff**
- Bins can be grouped using bins specification

```
enum { red, green, blue } color;

covergroup cg @(posedge clk);
   coverpoint color iff(! reset);
endgroup
```

filter condition

Defining Bins for Coverage Points

- If no state or transition bins explicitly defined, then bins are automatically created
  - Easy-to-use, no effort in defining bins
- Or, user can define state and/or transition bins for each coverage point.
  - Too many values
  - Not all values are interesting or relevant
- Each bin groups a set of values or a set of value transitions associated with a sampled variable or expression
  - Group equivalent values
  - Cover bins, not values

Defining coverage-point bins

```
bins name [ [ ] ] = { value_set } [ iff (expression) ]
bins name [ [ ] ] = ( transitions ) [ iff (expression) ]
bins name [ [ ] ] = default [sequence] iff (expression)]
```

- Group specific cover-points under a name
  - Set of values `{ 1, 5, [7:14], 25 }`
  - Set of transitions `( 4->5, 6->7, 10->1 )`
- **default** catches undefined values / transitions
- **[ ]** specifies creation of multiple bins per value
- **iff** specifies conditional coverage

Defining value coverage bins

```
bit [7:0] v_a, v_b;

covergroup cg @ev1;
  coverpoint v_a + v_b
  {
    bins a = { [64:127],200 };  // user-defined bins
    bins b[] = { 0,10,100,220 } iff( !reset );
    bins bad = default;         // all other values
  }
endgroup
```

- a creates one bin, covered if in the range
- b creates one bin per value: b[0], b[10], b[100], b[220]
  - only covered when reset == 0
- bad catches all other (in one bin)
  - [1:9], [11:63], [128:199], [201:219], [221:255]

Transition coverage bins

```
trans_range_list-> trans_range_list {-> tras_range_list}
trans_range_list ::=
        trans_item
      | trans_item [* repeat_range ]      // consecutive
      | trans_item [*-> repeat_range ]  // goto-repetition
      | trans_item [*= repeat_range ]   // nonconsecutive rept
```

Subset of property syntax

- {1:8} -> 2 expands to 1->2, 2->2, 3->2,… 8->2
- 3->5->{1:2} expands to 3->5->1 , 3->5->2
- 2->3[*2:3] expands to 2->3, 2->3->3, 2->3->3->3
- 2->3[*->2] expands to 2->3->…->3->…->3
- 2->4[*=2] expands to 2->4->…->4->…->4 (excluded)

Defining transition bins

```
bit [7:0] v_a;

covergroup cg @ev1;
  coverpoint v_a
  {
    bins v = { [10:100],200 };
    bins t[] = {1:2}->{2:3}
    bins s = (4 -> 5 -> 6, {[7:8],9}->{1,2});
    bins bad = default;
  }
endgroup
```

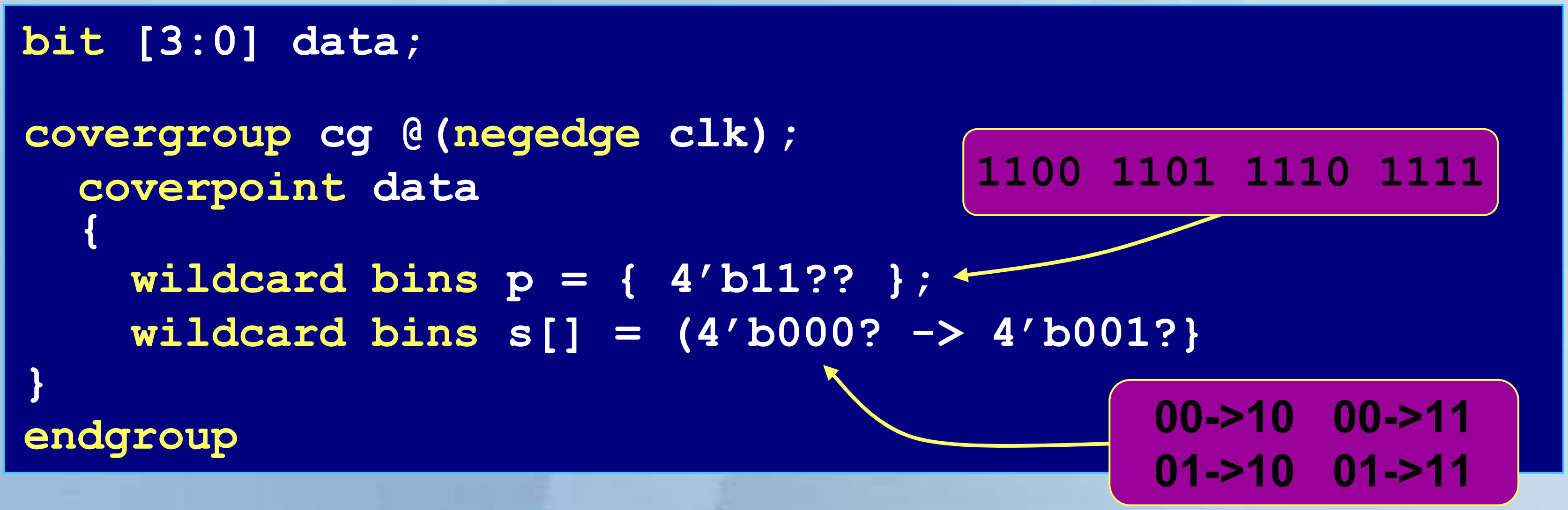
1->2, 1->3, 2->2, 2->3

4->5->6
7->1, 8->1, 9->1
7->2, 8->2, 9->2

- t creates one bin per transition: 4 bins
  - 1->2   1->3   2->2   2->3
- s creates one bin for all 7 transitions
- bad catches all undefined values
  - [0:9], [101:199], [201:255]

Wildcard bins specification

- The **wildcard** specification treats ?, X, Z as a wildcard for 0 or 1



```
bit [3:0] data;

covergroup cg @(negedge clk);
  coverpoint data
  {
    wildcard bins p = { 4’b11?? };
    wildcard bins s[] = (4’b000? -> 4’b001?}
}
endgroup
```

1100 1101 1110 1111

00->10 00->11
01->10 01->11

- p creates one bin for the 4 values
  - 12 , 13 , 14 , 15
- s creates one bin for each of the transitions
  - 0->2 , 0->3 , 1->2 , 1->3

Automatic bin creation

- If omitted, *N* bins are automatically created
- *N* is determined:
  - For an enum : *N* is the cardinality of the enum
  - All others: *N* is **min(2^M , auto_bin_max)**
    - M => # bits needed to represent the cover-point
- If *N* < 2^M
  - Values are uniformly distributed into the *N* bins
  - Every bin will include $2^M/N$ values
  - Last bin accommodates any *slack*

- Automatic bins exclude X and Z (2-state only)
- Coverage space is tractable

Excluding values or transitions

- Any set of values or transitions can be explicitly excluded from coverage
  - the **ignore_bins** specification

```
covergroup g1 @(posedge clk);
  coverpoint a
  {
    ...
    ignore_bins ivals = {7,8};
    ignore_bins itrans = (1->3->5);
  }
endgroup
```

- ivals excludes values 7 and 8
- itrans excludes the transition 1->3->5

Illegal values or transitions

- Any set of values or transitions can be marked illegal using **illegal_bins**

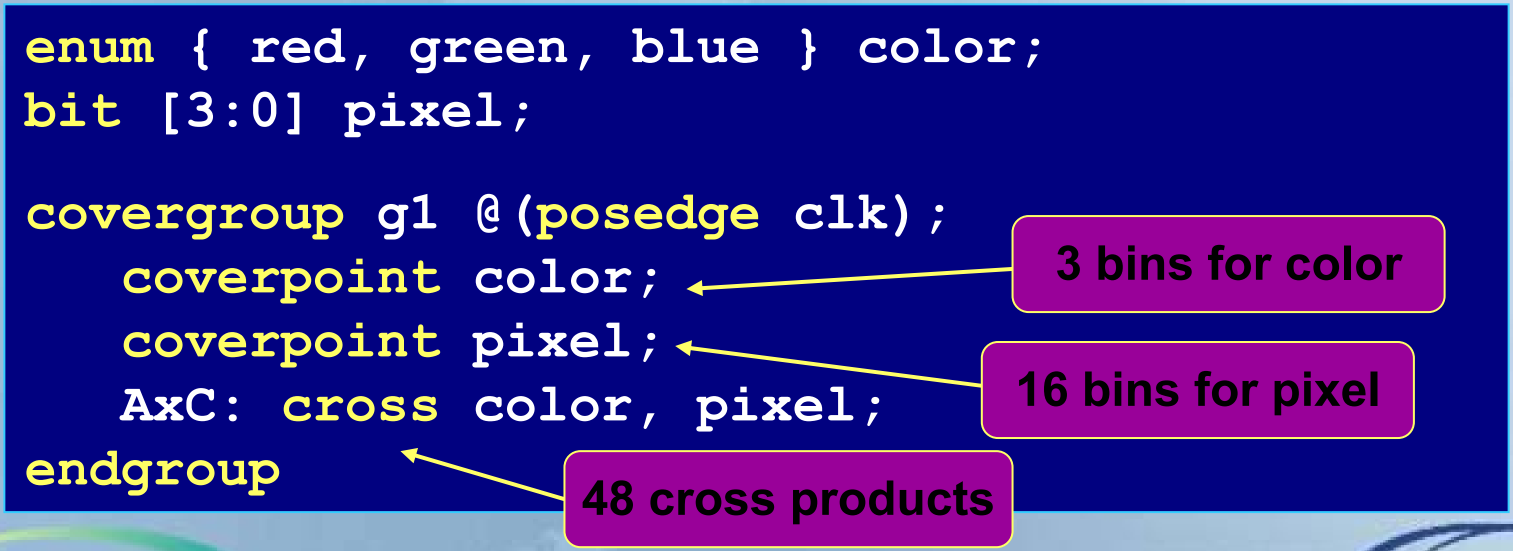
```
covergroup g1 @(posedge clk);
  coverpoint a
  {
    ...
    illegal_bins evals = {1,2,3};
    illegal_bins etrans = (4->3->2, 5->2);
  }
endgroup
```

- An Illegal bin hit triggers a run-time error
  – Even if it is part of another bin

Defining cross coverage

[label :] **cross** coverpoint_list [**iff** (expression)]
{ select_bins_or_options }

- Covers two or more coverage points simultaneously
  - Coverage of all combinations of all bins associated with the specified cover-points
  - The Cartesian product of all the sets of coverage-point bins



```
enum { red, green, blue } color;
bit [3:0] pixel;

covergroup g1 @(posedge clk);
    coverpoint color;
    coverpoint pixel;
    AxC: cross color, pixel;
endgroup
```

3 bins for color

16 bins for pixel

48 cross products

Defining cross coverage bins

- A cross coverage bin associates a name and a count with a set of cross products
- Cross bins group together sets of cross products

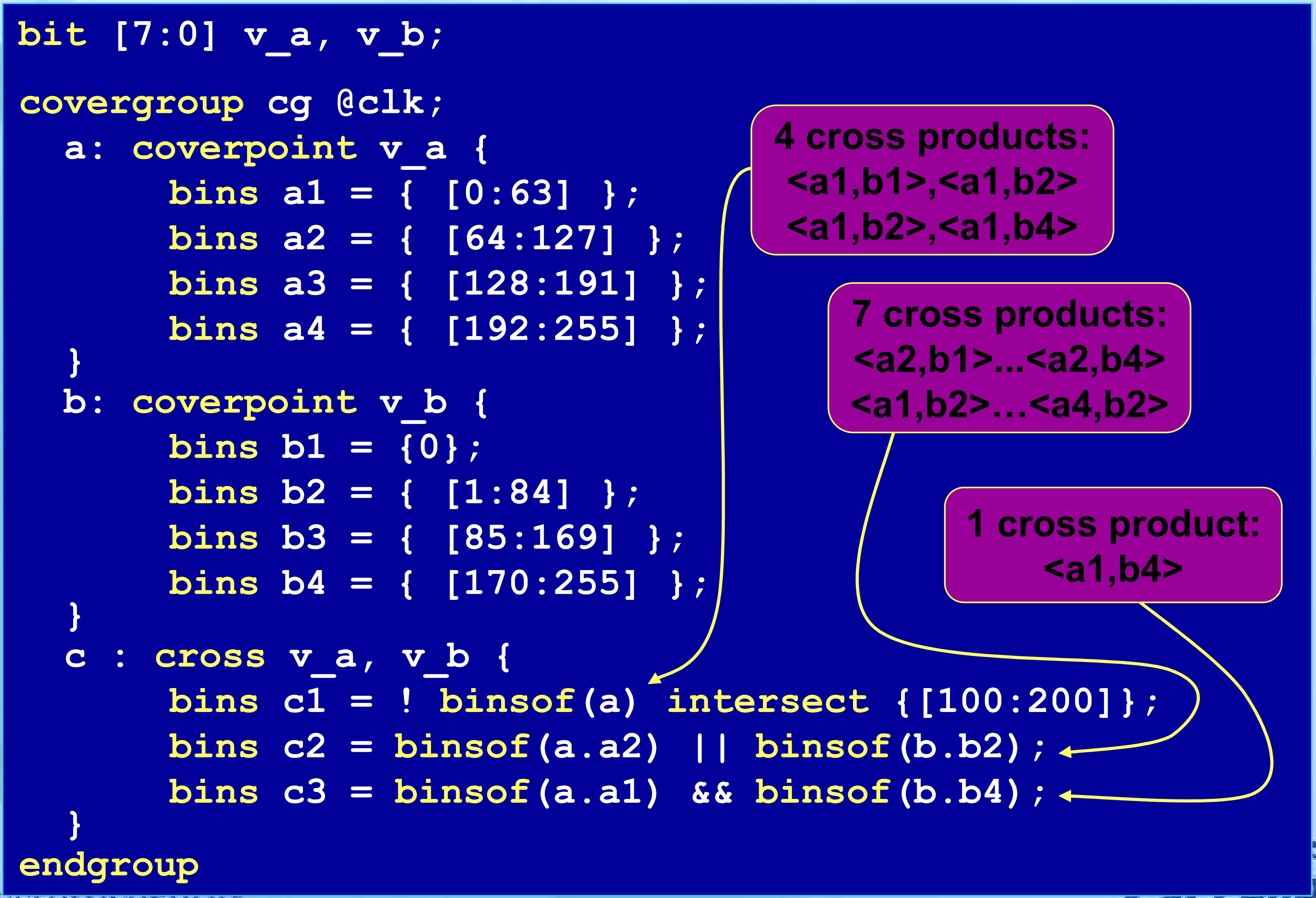
```
bins_selection ::= bins name = select_expression
 select_expression ::=
      select_condition
    | ! select_condition
    | select_expression && select_expression
    | select_expression || select_expression
    | ( select_expression )
select_condition ::=
  binsof ( bins) [ intersect open_range_list  ]
```

Cross coverage bins

```
bit [7:0] v_a, v_b;

covergroup cg @clk;
  a: coverpoint v_a {
       bins a1 = { [0:63] };
       bins a2 = { [64:127] };
       bins a3 = { [128:191] };
       bins a4 = { [192:255] };
  }
  b: coverpoint v_b {
       bins b1 = {0};
       bins b2 = { [1:84] };
       bins b3 = { [85:169] };
       bins b4 = { [170:255] };
  }
  c : cross v_a, v_b ;




endgroup
```

16 cross products:
<a1,b1>...<a1,b4>
<a4,b1>…<a4,b4>

Cross coverage bins



```
bit [7:0] v_a, v_b;

covergroup cg @clk;
  a: coverpoint v_a {
       bins a1 = { [0:63] };
       bins a2 = { [64:127] };
       bins a3 = { [128:191] };
       bins a4 = { [192:255] };
  }
  b: coverpoint v_b {
       bins b1 = {0};
       bins b2 = { [1:84] };
       bins b3 = { [85:169] };
       bins b4 = { [170:255] };
  }
  c : cross v_a, v_b {
       bins c1 = ! binsof(a) intersect {[100:200]};
       bins c2 = binsof(a.a2) || binsof(b.b2);
       bins c3 = binsof(a.a1) && binsof(b.b4);
  }
endgroup
```

4 cross products:
<a1,b1>,<a1,b2>
<a1,b2>,<a1,b4>

7 cross products:
<a2,b1>...<a2,b4>
<a1,b2>…<a4,b2>

1 cross product:
<a1,b4>

Exclusion cross products

- Select expressions can be used to exclude or specify cross products as illegal

```
covergroup yy;
  cross a, b
  {
    ignore_bins x = binsof(a) intersect {5,[1:3]};
    illegal_bins x = binsof(a) intersect {[25:$]};
  }
endgroup
```

bins to be excluded

illegal bins

- Illegal bins take precedence over all others
- Excluded bins are never included

Generic Coverage groups

- Generic coverage groups can be written by passing their traits as arguments to the constructor.

```
covergroup rg (ref int ra, int low, int high ) @(clk);
   coverpoint ra                // sample variable passed by reference
   {
     bins good = { [low : high] };
     bins bad[] = default;
   }
endgroup
```

- good creates one bin, for the range [low : high]
- bad creates one bin per value outside that range

```
int A, B;

rg c1 = new( A, 0, 50 );        // cover A in range 0 to 50
rg c2 = new( B, 120, 600 );     // cover B in range 120 to 600
```

Coverage Group in classes

- Coverage groups may be embedded in class
  - Integrated with object oriented paradigm
  - Intuitive and simple to cover data members
    - Including private data members
  - Other class members can be seamlessly used in coverage specification

Embedded Coverage Group

```
class xyz;
    bit [3:0] m_x;
    int m_y;
    bit m_z;

    covergroup cov1 @m_z;     // embedded covergroup
      coverpoint m_x;
      coverpoint m_y;
    endgroup

    function new(); cov1 = new; endfunction
endclass
```

Coverage Options

```
covergroup g1 (int w, string iComment) @(posedge clk) ;
  // track coverage information for each instance of g1
  option.per_instance = 1;
  option.comment = iComment; // comment for each
                             // instance of g1
    a : coverpoint a_var
    {
      option.auto_bin_max = 128;
    }
    b : coverpoint b_var;
   {
       // contributes w times more than a and c1
      option.weight = w;
   }
   c1 : cross a_var, b_var ;
endgroup
```

creates 128 bins max

contributes w times more

Options for control

- **weight**
  - for computing weighted mean
- **goal**
  - target goal for group/point/cross
- **name**
  - name for the covergroup instance
- **at_least**
  - minimum number of hits for a bin
- **per_instance**
  - keep per instance data in addition to the cumulative coverage

Coverage Control

- Covergroup and covergroup instance methods allow control and access to the coverage data
- **void sample**()
  - Procedurally control sampling
- **real get_coverage**()
  - obtains cumulative coverage
- **real get_inst_coverage**()
  - obtains instance coverage

Procedural sampling

```
enum { red, green, blue } color;
bit [3:0] pixel_adr,

covergroup g1;
  c: coverpoint color;
  a: coverpoint pixel_adr iff (xfer > n);
endgroup;

g1 tc1 = new;
task transaction();
  ...
  tc1.sample();
  ...
endtask
```

Sample for coverage at this point

Coverage Control

- Methods to start and stop collection
  - **start**()
  - **stop**()
- System function to retrieve overall coverage
  - **$get_coverage**()
- System tasks to name, load and save coverage database
  - **$set_coverage_db_name**()
  - **$load_coverage_db**()

Thank you