Low Power Coverage:
The Missing Piece in Dynamic Simulation

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Agenda: Part One- Problem Formulation

- Identify the Contributors of Low-Power (LP) Coverage data
  - UPF and relevant HDL objects.
- Discuss LP Coverage Computation Uniqueness
  - Power States and Power State Transitions
  - How they are different from non-LP state machines.
- The Missing Piece to Complete LP Coverage Computation Models
  - Semantics for formation of Power State Machines/State-Transition
  - Adaptable database with API

    - to collect, access and represent the Computed LP Coverage.

Agenda: Part Two- Proposed Solution

- To fulfill these missing pieces,
  - First identified all the resources of the LP coverage contributors
  - Categorized them in *UPF cover-bins*
  - Further identified *UPF cross-cover-bins* in a complex hierarchical UPF flow
  - Proposed Adaptable and Universal Coverage Database

- Bonus – Explanation with Examples and Case Studies,

PART ONE:
PROBLEM FORMULATION

What is Coverage?

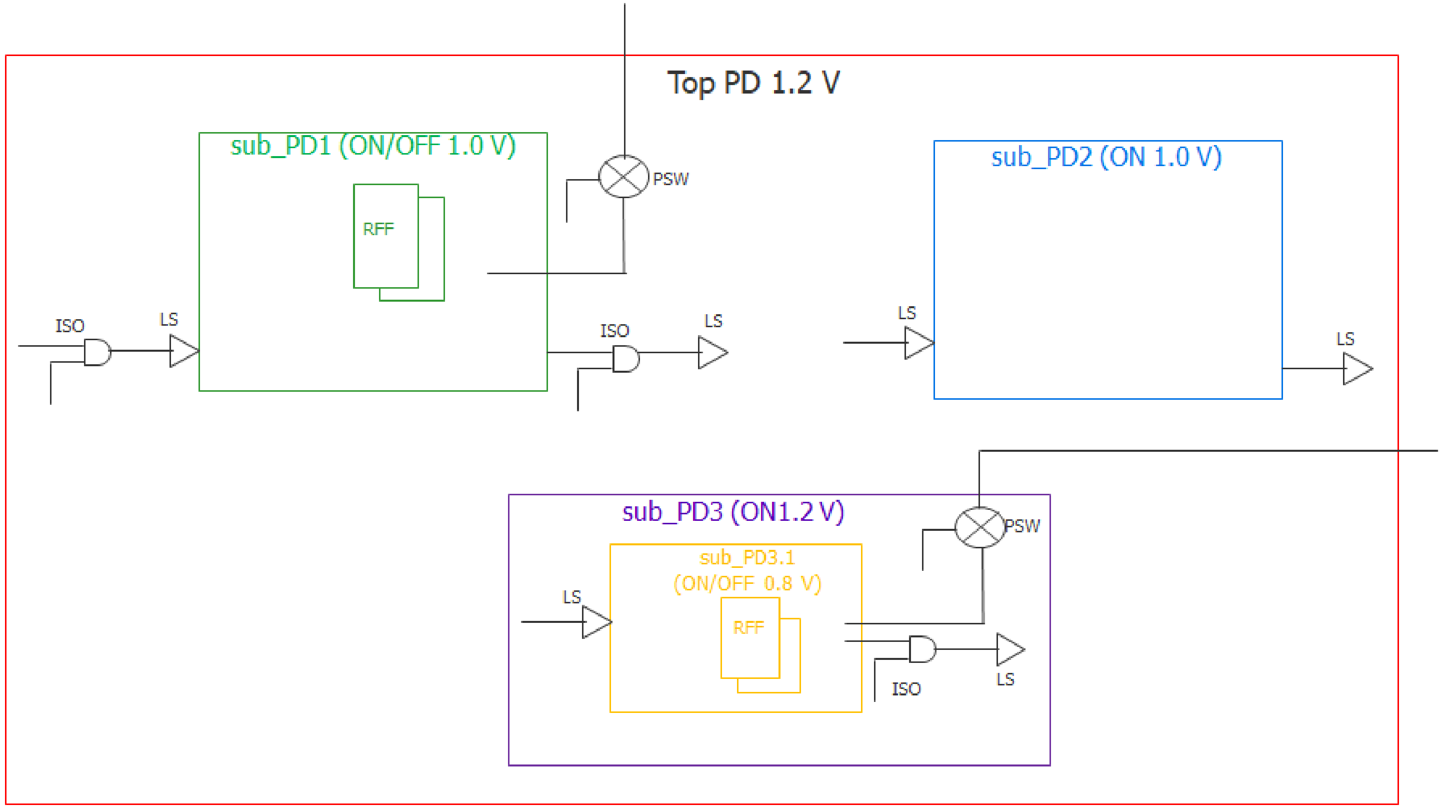
- Coverage - Meaningful insight into design verification completeness
- Coverage Metric- Standardize Verification Measurement
  - Describe the degree to which the design is exercised
    - With certain design objects or parameters for a particular test suite / testplan execution
    - Even the test Recapitulated to contribute to the total resultant coverage metric for the design.
  - Resultant metrics are stored in a common, unified coverage database (UCDB).
- UCDB – Allows Accessibility to further enhance the Coverage Metrics
  - With new coverage results from different new sources through coverage merging,
  - Mechanism to analyze and generate the coverage reports through API,
    - e.g. Industry standard Accellera UCIS API.

What is Low-Power (LP) Coverage?

- LP Coverage
  - Originates from the abstraction of UPF & Relevant HDL Objects.
- In a LP Dynamic Simulation State Space,
  - Power States and Power State Transitions are asynchronous in nature
  - Power States may refer or depend on other power states
  - Even more than one power state can remain true at a time
  - While it is possible to mark any power state as illegal anytime.
- The Unique & Contradictory nature with non-LP State Machines
  - Make it difficult to formulate LP coverage computation models and
  - Coordinate with standard database like UCDB

Foundations of LP-DV Concepts

- UPF Objects
  - Power Domains
  - Power Supplies
  - Power States
  - Power Strategies, etc.



Characteristics of Power States

- Power states nature
  - Abstract at higher levels and Physical (supply port and nets) at lower levels of designs
- Power States are for
  - Different UPF objects –
    - e.g. Power Supplies, Power Domains, Design Groups, design models, and design instances
- Power states may
  - Denote different operation modes based on
    - Different combinations of Power Domains and their Power Supplies,
    - Reference descendant power domains or power supply states
    - Subject to interdependency between different UPF objects

Key Contributors of LP Coverage

What are the 'Sources of Power States and Their Transitions'?

UPF Constructs like:

- Supply Port States from **add_port_state,**
- Supply Net States from Power State Table (PST),
- PST States from **add_pst_state**,
- Power Domain States from **add_power_state**,
- Supply Port, Supply Net, and Supply Set Function States from **add_supply_state,**
- Power States of the Power Supply Sets from **add_power_state,** etc.

Key Contributors of LP Coverage

Other Sources of ‘Power States and Power State Transitions’?

UPF Strategies

- Isolation “Enable” Signal
- Retention “Save and Restore” Signals
- Power Switch ‘States’ and Power Switch ‘State Transitions’
- Power Switch “Control Port”
- Power Switch “Ack Port”

Key Contributors of LP Coverage

Transitions of Control Signals for UPF Strategies

- High-to-Low &
- Low-to-High Transitions

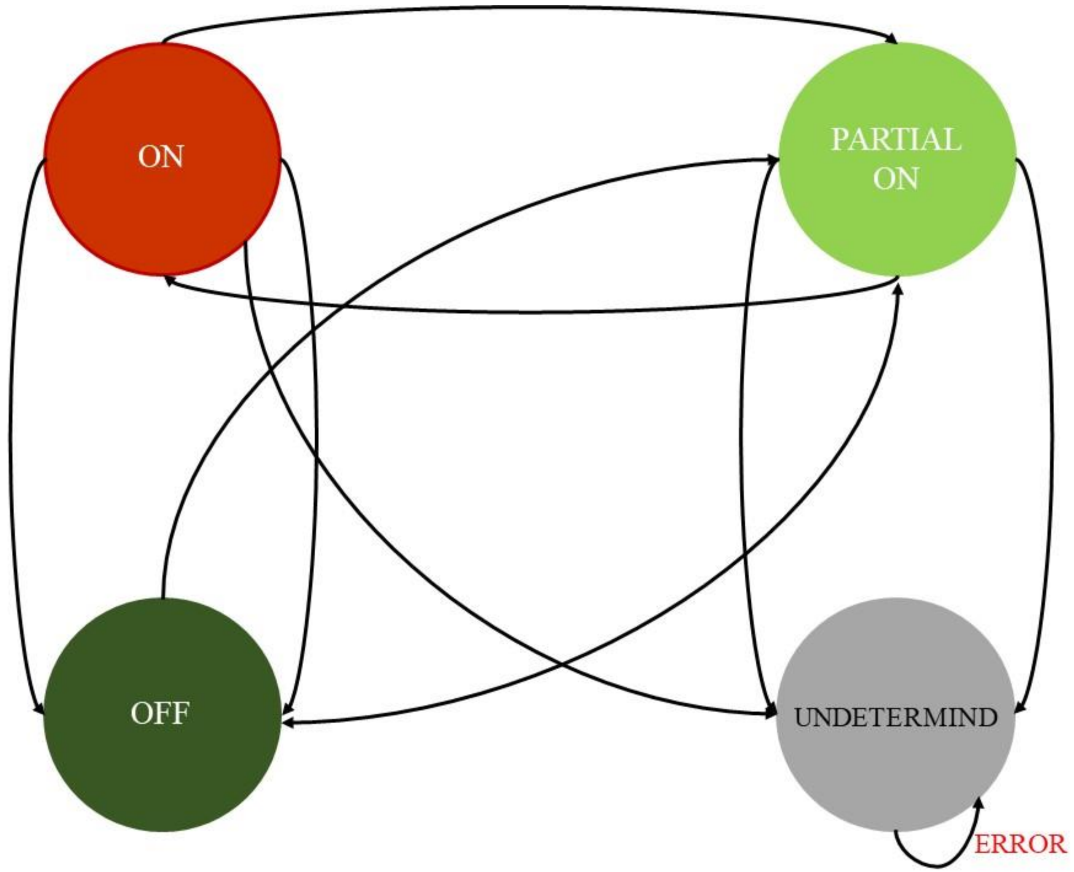
States of Control Signals for UPF Strategies

- Active
  - Through presenting a value (level sensitive) or
  - Transition (edge sensitive),
- Inactive (opposite to the active)
- Active x (driving unknown)
- Active z (remain floating or un-driven)

Key Contributors of LP Coverage

State Values of Power Switch, Control, and Acknowledge Ports

- ON state,
- OFF state,
- Partial ON state and
- UNDETERMINED (ERROR) state.



PART TWO:
PROPOSED SOLUTION

Proposed Foundation on LP Coverage

- **Whenever the design encounter the '*Key Contributors*'**
  - LP-SIM or coverage analytical engine will generate *UPF cover-bins*.
  - We define *UPF cover-bins*, as shown below

***UPF cover-bins**: This is a counter construct with specific decorated items. These items are generalized and based on UPF coverage constructs, i.e.*

- *name of state,*
- *status (legal/illegal),*
- *scope (design scope),*
- *attribute (ports or nets) etc.*

The UPF cover-bins represents LP coverage data collected from corresponding UPF coverage constructs.

LP Coverage from LP Dynamic Checks

May Based on;

- LP testbench and LP augmented RTL (Code Coverage),
- Automated LP Sequence Checkers (ISO, Save/Restore Toggle etc.)
- Custom LP Checkers (bind_checker)

LP Coverage from Power States and Power State Transitions

May Based on

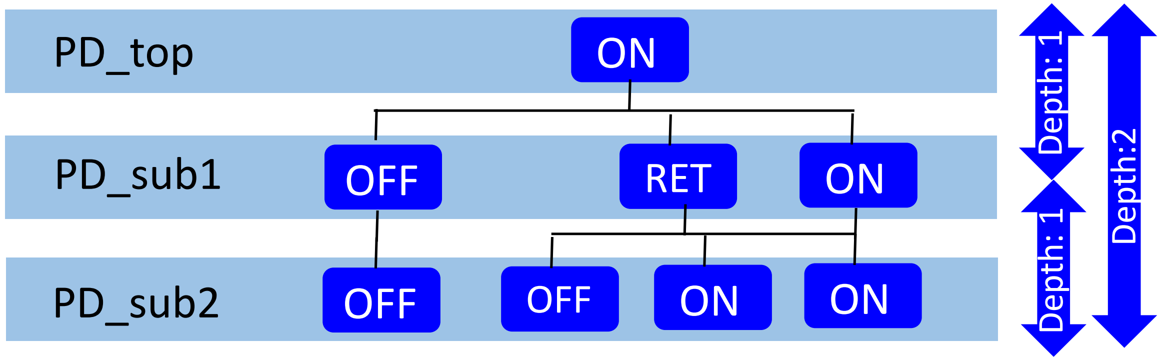
- Design controls,
- Supply ports and nets created in the UPF and design,
- Power domains and their power states,
- Supply sets and their states,
- Power Switch States and their Transitions,
- State transitions for ISO, RFF, PSW Control and Ack signals,

Coverage from Cross-Power Domain Power States Dependency

May Based on

- All possible combinations of interdependent power states,
- As well as their possible spontaneous transitions.

add_power_state PD_top -state SYS_ON {-*logic_expr* {PD_sub1 == SUBSYS1_ON && PD_sub2 == SUBSYS2_ON}}
add_power_state PD_top -state SYS_OFF {-*logic_expr* {PD_sub1 == SUBSYS1_OFF && PD_sub1== SUBSYS1_RET && PD_sub2 == SUBSYS2_OFF}}



Additional Proposal for the Foundation of LP Coverage

Cross-Power Domain Power States Dependency

- In hierarchical UPF flow
  - Power states and transitions are highly interdependent,
- A new ***UPF cross-cover-bins*** are defined

- ***UPF cross-cover-bins***
  - Extensions of ***UPF cover-bins***,
  - But possess additional decoration items to determine the depth of hierarchical crossings

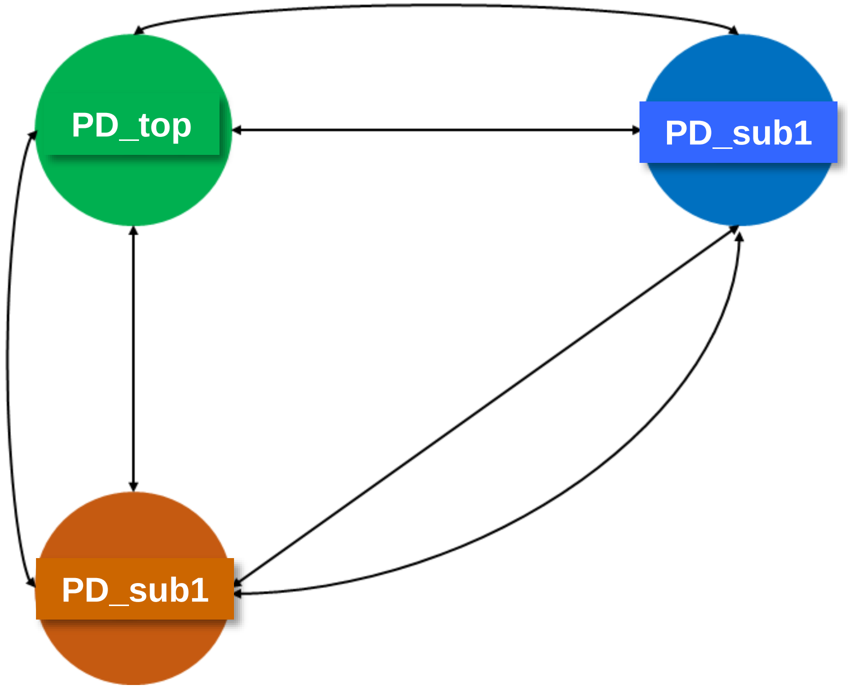
UPF cross-cover-bins

Semantically Extended

describe_state_cross_coverage
[-***domains*** domains_list]
[-***depth*** cross_coverage_depth]

Dependency Unfolded from Graph

Power Domains	PD_top	PD_sub1	PD_sub2
Power States	SYS_ON	SUBSYS1_ON	SUBSYS2_ON
Power States	SYS_ON	SUBSYS1_RET	SUBSYS2_ON
Power States	SYS_OFF	SUBSYS1_OFF	SUBSYS2_OFF



Cross-Coverage Data for *-depth*=1 (default) for PD_top -to> PD_sub1 -to> PD_sub2

SYS_ON –to > SUBSYS1_ON –to > SUBSYS2_ON
SYS_ON –to > SUBSYS1_RET –to > SUBSYS2_ON
SYS_OFF –to > SUBSYS1_OFF –to > SUBSYS2_OFF

Case Study: Coverage Computation for UPF Cross-Cover-Bins

add_power_state PD_OUT ***-state*** PD_OUT_on {-***logic_expr*** {PD_OUT***.primary*** == PD_OUT_primary_on}}

add_power_state PD_OUT ***-state*** PD_OUT_off {***-logic_expr*** {PD_OUT***.primary*** == PD_OUT_primary_off}}

add_power_state PD_OUT ***-state*** PD_OUT_ret {***-logic_expr*** {PD_OUT***.primary*** == PD_OUT_primary_off && PD_OUT.default_retention == PD_OUT_ret_on}}

add_power_state PD_OUT2 ***-state*** PD_OUT_on {***-logic_expr*** {PD_OUT == PD_OUT_on}}

add_power_state PD_SUBSYS2 ***-state*** PD_SUBSYS2_on \
{***-logic_expr*** {PD_SUBSYS2***.primary*** == PD_SUBSYS2_primary_on}}

configure cross coverage
describe_state_cross_coverage *-domains* {PD_SYS} -***depth*** 3
describe_state_cross_coverage *-domains* {PD_SUBSYS1} -***depth*** 2
describe_state_cross_coverage *-domains* {PD_OUT2}

Case Study: Coverage Computation for UPF Cross-Cover-Bins

```
---------------------------------------------------------------------------------------
UPF OBJECT                                             Metric      Goal    Status
---------------------------------------------------------------------------------------
 TYPE : POWER STATE CROSS
/alu_tester/dut/PD_SYS(ID:PD1),
/alu_tester/dut/PD_SUBSYS2(ID:PD2),
/alu_tester/dut/PD_SUBSYS1(ID:PD3),
/alu_tester/dut/PD_OUT2(ID:PD4),
/alu_tester/dut/PD_OUT(ID:PD5)
                                            100.00%       100    Covered
 POWER STATE CROSS coverage instance
\/alu_tester/dut/pa_coverageinfo/PD_SYS/PD_SYS_PS_CROSS/PS_CROSS_PD_SYS
                                            100.00%       100    Covered
   Power State Cross                                   100.00%       100    Covered
      bin \PD1:SLEEP-PD2:PD_SUBSYS2_off                      2          1    Covered
      bin \PD1:RUN-PD2:PD_SUBSYS2_on-PD3:PD_SUBSYS1_on-PD4:PD_OUT_on-PD5:PD_OUT_on
                                                 2          1    Covered
```

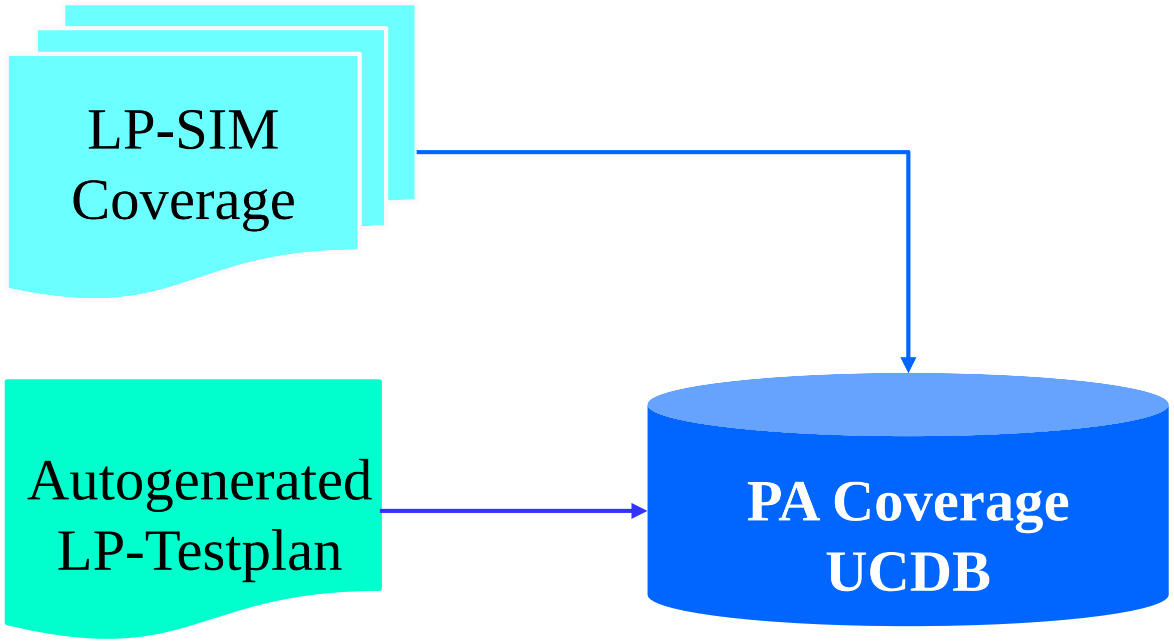
Case Study: Coverage Computation for Power State Transitions

```
# PSW example for Collecting State Transition Coverage
create_power_switch IN_sw \
    -domain PD_SUBSYS2 \
    -output_supply_port {vout_p VDD_IN_net} \
    -input_supply_port {vin_p MAIN_PWR_moderate} \
    -control_port {ctrl_p IN_PWR} \
    -on_state {normal_working vin_p {ctrl_p}} \
    -off_state {off_state {!ctrl_p}}

# controlling State Transition Coverage by UPF for PSW (IN_sw) shown above
add_state_transition -model IN_sw \
                -transition {t0 -from {ON} -to {}} \
                -transition {t1 -from {ON} -to {OFF}} \
                -transition {t2 -from {ON} -to {}} \
                -transition {t3 -from {ON} -to {ERROR} -illegal}
```

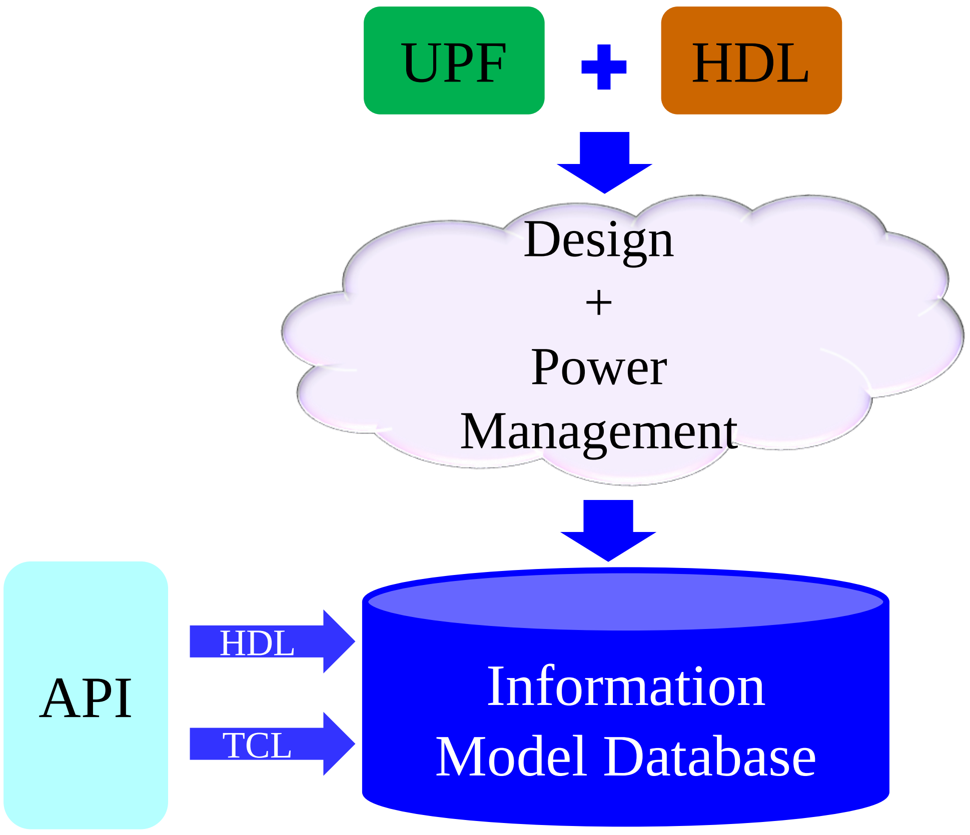
Case Study: Coverage Computation for Power State Transitions

```
--------------------------------------------------------------------------------------------
UPF OBJECT                                         Metric       Goal    Status
--------------------------------------------------------------------------------------------

 TYPE: Power Switch /cpu_tester/dut/IN_sw              0.00%        100    ZERO
 Power Switch coverage instance \/cpu_tester/dut/pa_coverageinfo/IN_sw/IN_sw_PS/PS_TRANS_IN_sw
                                          0.00%        100    ZERO
   Power State Transitions                              0.00%        100    ZERO
      illegal_bin ON -> ERROR                              0                ZERO
      illegal_bin ON -> PARTIAL_ON                           0                ZERO
      illegal_bin ON -> OFF                             2               Occurred
      bin dummy                                  0          1    ZERO
 TYPE: Power Switch Control Port /cpu_tester/dut/IN_sw/ctrl_p
                                          50.00%        100    Uncovered
 Power Switch Control Port coverage instance \/cpu_tester/dut/pa_coverageinfo/IN_sw/ctrl_p/PS_ctrl_p
                                          50.00%        100    Uncovered
   Power State ACTIVE_LEVEL                              100.00%        100    Covered
      bin ACTIVE                                 4          1    Covered
   Power State INACTIVE                              100.00%        100    Covered
      bin ACTIVE                                 2          1    Covered
   Power State ACTIVE_Z                                0.00%        100    ZERO
      bin ACTIVE                                 0          1    ZERO
   Power State ACTIVE_X                                0.00%        100    ZERO
      bin ACTIVE                                 0          1    ZERO
 Power Switch Control Port coverage instance \/cpu_tester/dut/pa_coverageinfo/IN_sw/ctrl_p/PS_TRANS_ctrl_p
                                          100.00%        100    Covered
   Power State Transitions                            100.00%        100    Covered
      bin HIGH_TO_LOW                                    2          1    Covered
      bin LOW_TO_HIGH                                    2          1    Covered
```

Case Study: Adhoc Approach for LP Coverage Database



Proposed Adaptive Coverage Database



Objects: Are primary holders of information

- They are accessed by handle ID / UPF Handle
- Objects represent UPF, HDL or a relationship between them
- So, there are three major classes of objects
- HDL Objects: Models objects that are representing HDL design
- UPF Objects: Models objects that are created by UPF
- Relationship Objects: Objects that model the relationship between UPF and HDL objects.

Properties: Are collection of information about an object

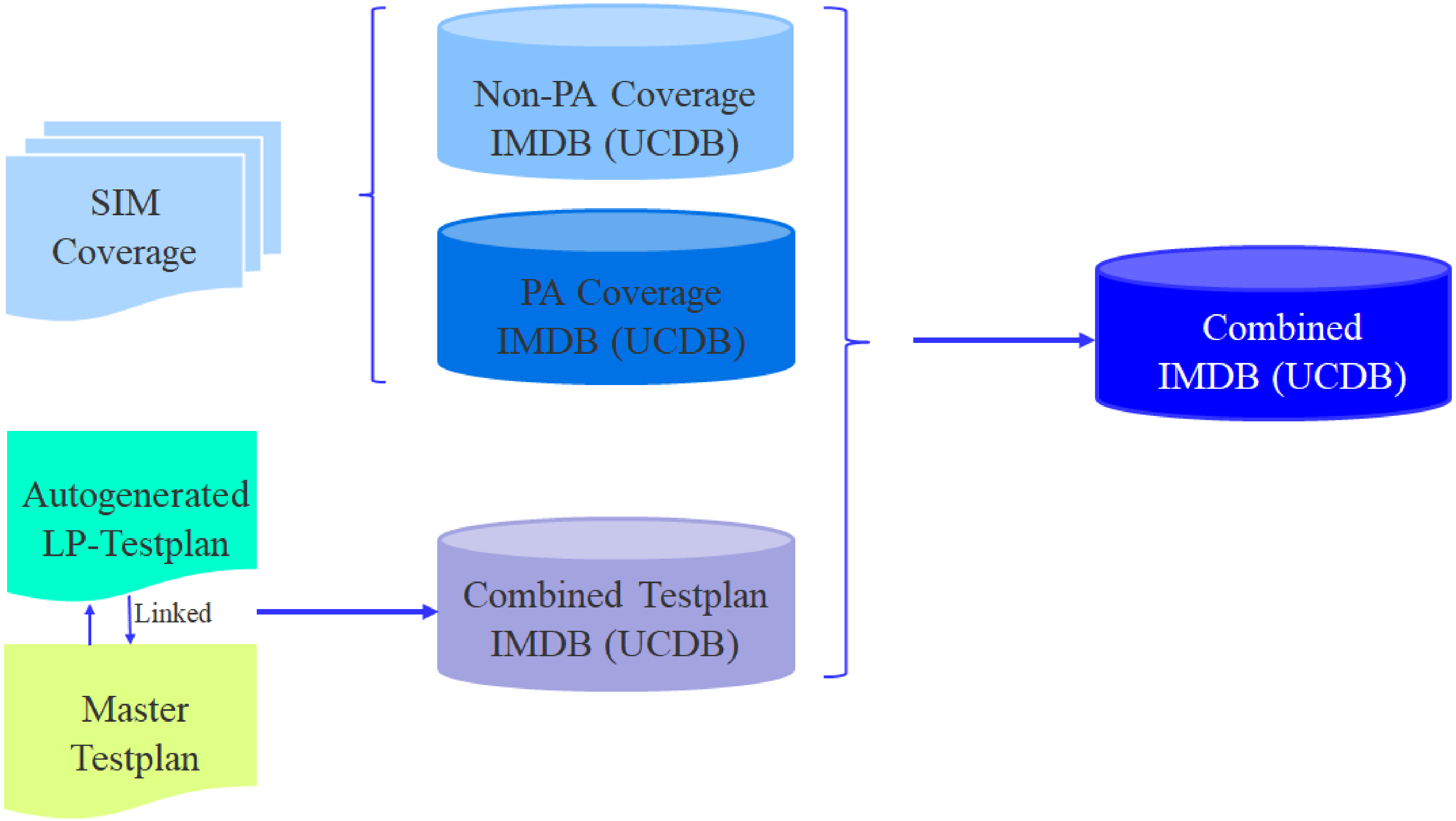
- They are accessed by property IDs
- Properties are classified into
- Basic Types: String, Integer, Boolean etc.
- Complex Types: Handle to properties, list of handles to other objects etc.
- Dynamic properties: Accessible only from the HDL package functions

Algorithm for Adaptive Coverage Database

Initiatives and Proposals at a Glance

- ✓ Identify the missing pieces of LP coverage modeling
- ✓ Identify the complete source of LP coverage contributors
- ✓ Define LP cover bins — the *UPF cover-bins* and *UPF cross-cover-bins*
- ✓ Identify LP coverage and testplan association mechanism through UCDB
- ✓ Implement standardization mechanism for LP coverage bins through IMDB defined by UPF 3.0
- ✓ Extend LP cover bins in IMDB as subset of UCDB
- ✓ Identify database accessibility through mapping HDL API defined by both UPF 3.0 and UCDB standards
- ✓ Propose adaptive coverage database through UPF 3.0 in IMDB and extend it with UCDB standard for integrating the non-LP coverage, And
- ✓ Identify the requirements of heterogeneous merge algorithms for merging LP and non-LP data in UCDB

Heterogeneous Merging of LP and non-LP Coverage in IMDB



Conclusions

- Completed the initial framework for ‘A Complete LP coverage’ Computation Model

- Also Standardization and integration with existing UCIS coverage database

- Further research is required to completely map
  - The functionalities of HDL API defined by both UPF 3.0 and UCDB standards