Software Quality Engineering

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Testing, Quality Assurance, and Quantiable Improvement
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Chapter 9. Boundary Testing

- Input Domain Partitioning
- Simple Domain Analysis and Testing
- Important Boundary Testing Strategies
- Extensions and Perspectives

Non-Uniform Partition Testing

- Extensions to basic partition testing ideas:

  Non-uniform partitioned testing.

  - Testing based on related problems
  - Usage-related problems => UBST
  - Boundary problems => What to do?
- Usage-related problems:
  - More use => more likely failures
  - Usage information in testing

    => (Musa's) operational profiles (OPs)
- Boundary problems (This Chapter):

  => input domain boundary testing (BT).

Boundary Testing: Overview

- What is it?
  - Test I/O relations.
  - Classifying/partitioning of input space:
    - case-like processing model.
  - Cover input space and related boundary conditions.
  - Also called (input) domain testing.
- Characteristics and applications?
  - Functional/black-box view

    (I/O mapping for multiple sub-domains)
  - Well-defined input data:
    - numerical processing and decisions.
  - Implementation information may be used.
  - Focus: boundaries and related problems.
  - Output used only in result checking.

I/O Variables and Values

- Input:
  - Input variables: x1; x2; ... ; xn.
  - Input space: n-dimensional.
  - Input vector: X = [x1; x2; ... ; xn].
  - Test point: X with specific xi values.
  - Domains and sub-domains:

    specific types of processing are defined.
  - Focus on input domain partitions.

- Output (assumed, not the focus)
    - Output variables/vectors/space/range similarly defined.
    - Mapped from input by a function.
    - Output only used as oracle.

Domain Partitioning and Sub-domains

- Input domain partitioning
    - Divide into sets of sub-domains.
    - "domain", "sub-domain", and "region" often used interchangeably
- A sub-domain is typically defined by a set of conditions in the form of:

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f (x1; x2; ... ; xn) < K

where "<" can also be substituted by ">","=", "<>", "<=", or ">=".
```

Domain Partitioning and Sub-domains

- Domain (sub-domain) boundaries:
    - Distinguishes/defines different sub-domains.
    - Each defined by it boundary condition,

      e.g., f (x1; x2; ...; xn) = K

    - Adjacent domains:

those share common boundary(ies)

- Boundary properties and related points:
    - Linear boundary:

      a1*x1 + a2*x2 + ... + an*xn = K

      (Otherwise, it is a nonlinear boundary.)

    - Boundary point: on the boundary.

    - Vertex point: 2+ boundaries intersect.
    - Other properties w.r.t. domains later.

Boundary and Domain Properties

- Boundary properties w.r.t domains:
    - Closed boundary: inclusive (<=, >=)
    - Open boundary: exclusive (<, >)
- Domain properties and related points:
    - Closed domain: all boundaries closed
    - Open domain: all boundaries open
    - Linear/nonlinear domain:

      all linear boundary conditions?

    - Interior point: in domain and not on boundary.

    - Exterior point: not in domain and not on boundary.

Input Domain Partition Testing

- General steps:
    - Identify input variable/vector/domain.
    - Partition the input domain into sub-domains.
    - Perform domain/sub-domain analysis.
    - Define test points based on the analysis.
    - Perform test and followup activities.
- Boundary testing: Above with focus on boundaries.

- Domain analysis:

- Domain limits in each dimension.
- Domain boundaries (more meaningful).
- Closure consistency?
- Plotting for 1D/2D, algebraic for 3D+.

Problems in Partitioning

- Domain partitioning problems:
  - Ambiguity: under-defined/incomplete.
  - Contradictions: over-defined/overlap.
  - Most likely to happen at boundaries.
  - Key: sub-domains form a partition.
- Related boundary problems:
  - Closure problem.
  - Boundary shift: f (x1; x2; : : : ; xn) = K + &
  - Boundary tilt: parameter change(s).
  - Missing boundary.
  - Extra boundary.

Simple Domain Analysis and EPC

- Simple domain analysis:
  - identify domain limits in each dimension
    - min, max values
  - push "over" max, "under" min

    => 4 values for each variable or dimension:

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    under, min, max, over
    ```
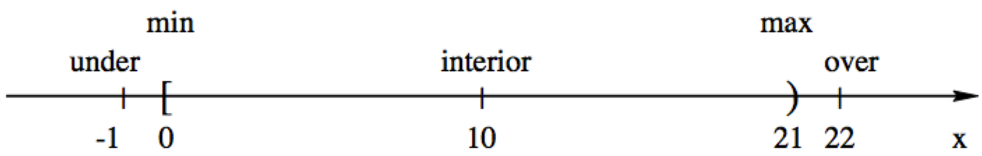
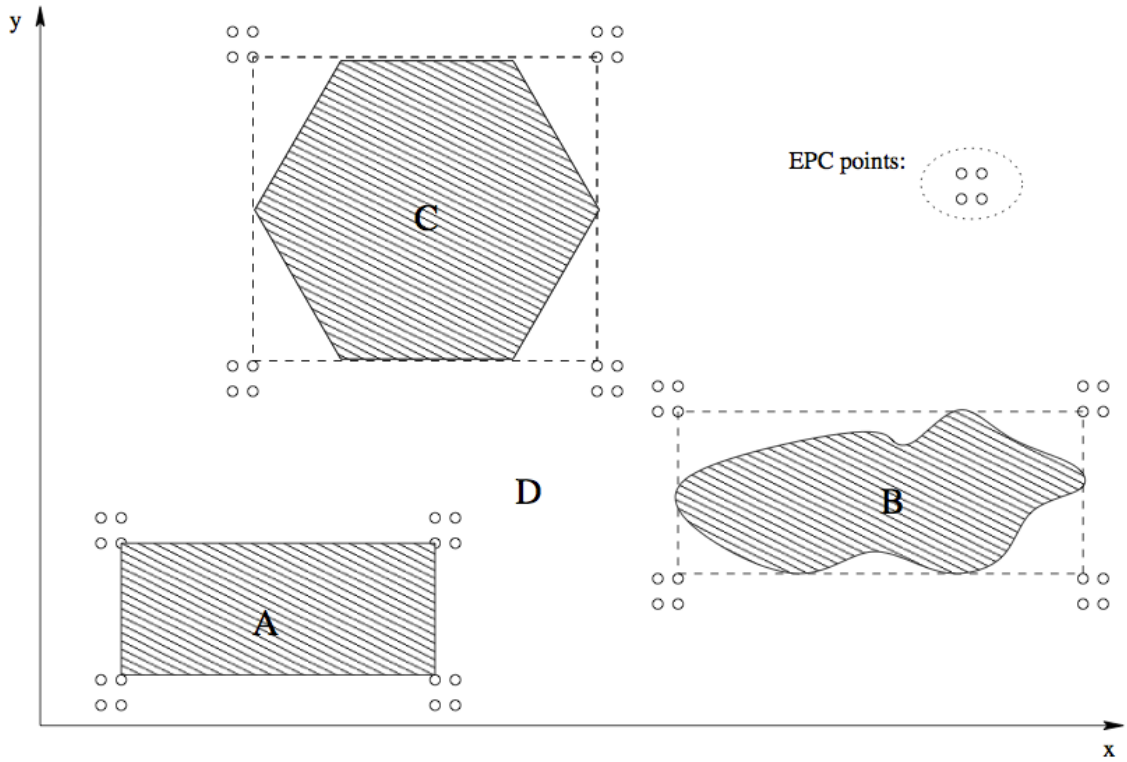

- 1D example: Fig 9.1 (p.133)



- Extreme point combinations (EPC)
  - Combine above to derive test points.
  - Combine variables ((cid:2), cross-product).
  - # testcases: 4^n + 1.

Simple Domain Analysis and EPC



- 2D examples: 9.2 (p.134)
- Problems/shortcomings with EPC:
    - Missing boundary points: 2D example.

      (unless boundaries perfectly aligned)
    - Exponential # testcases: 4^n + 1. => Need more effective strategies.

Boundary Testing Ideas

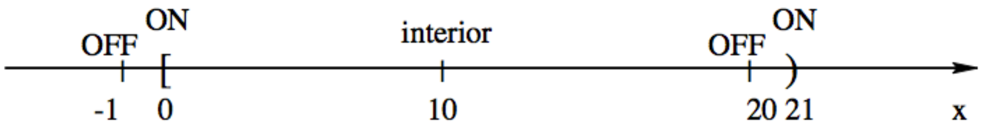
- Using points to detect boundary problems:
    - A set of points selected on or near a boundary: ON and OFF points.
    - Able to detect movement, tilt, etc.
    - Motivational examples for boundary shift.
- E neighborhood and ON/OFF points
    - Region of radius - around a point
    - Theoretical: could be infinitesimal
    - Practical: numerical precision
    - ON point: On the boundary
    - OFF point:
        - opposite to ON processing
        - off boundary, within - distance
        - closed boundary, outside
        - open boundary, inside

Weak N x 1 Strategy

- N x 1 strategy (N-dimensional space)
    - N ON points (linearly independent):

      confirm (n-1)-D hyper-plane boundary.
    - 1 OFF point: centroid of ON points.
    - 1D: 1 ON, 1 OFF

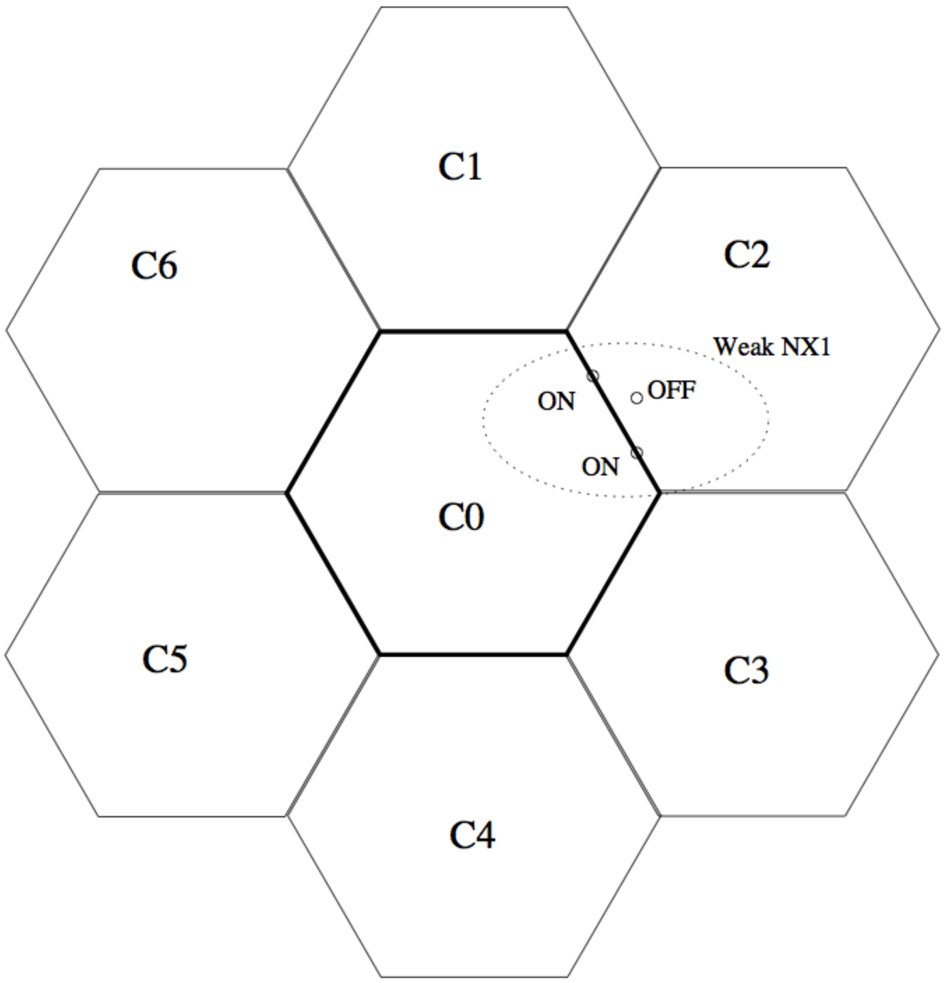
- 1D examples: Fig 9.3 (p.137)



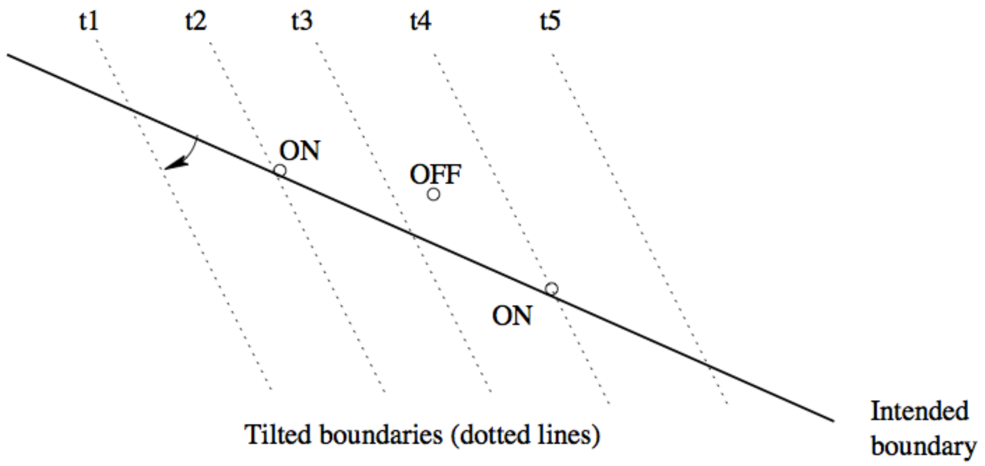
- Typical errors detected:
    - Closure bug
    - Boundary shift
    - Boundary tilt (later)
    - Extra boundary (sometimes)
    - Missing boundary

Weak N x 1 Strategy

- N x 1: N ON and 1 OFF points
    - Weak: set of tests per boundary instead of per boundary segment.
    - #test points: (n + 1) (cid:2) b + 1
    - 2D example: Fig. 9.4 (p.137) below
        - advantages over EPC!



Weak N x 1 Strategy

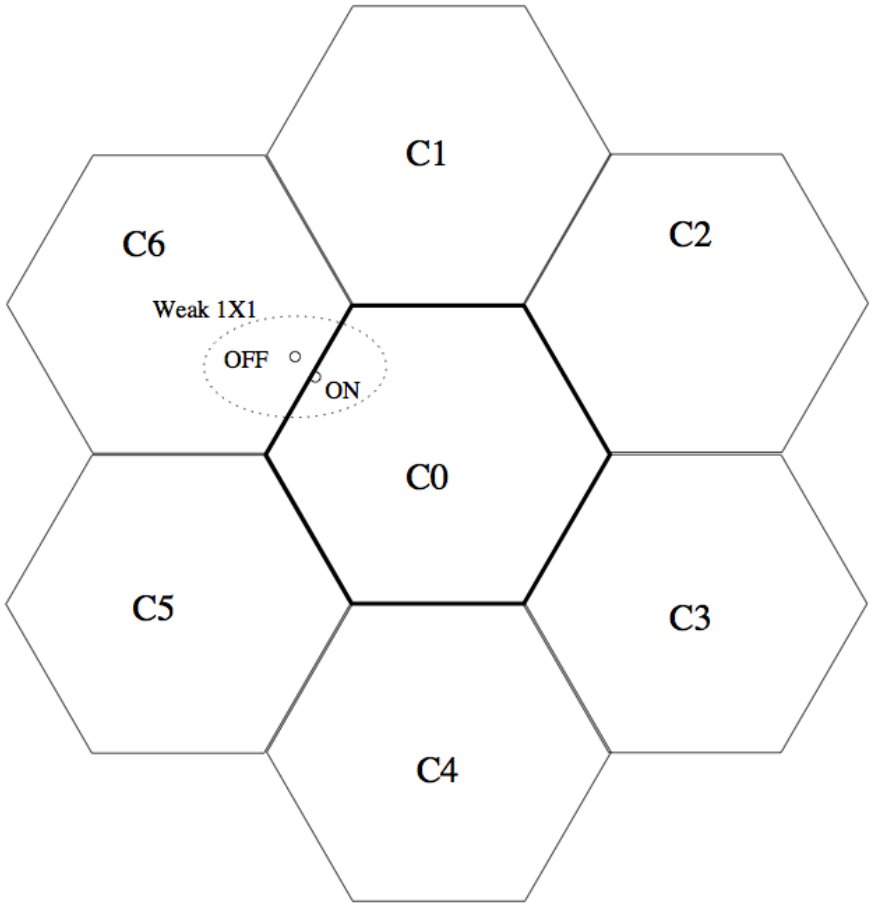


- Boundary tilt: Fig 9.5 (p.138) above
  - series of tilting points
  - some ON/OFF points combination will detect each tilt
  - (moving) illustration in class
- Other problems detected (cid:25) 1D example

Weak 1 x 1

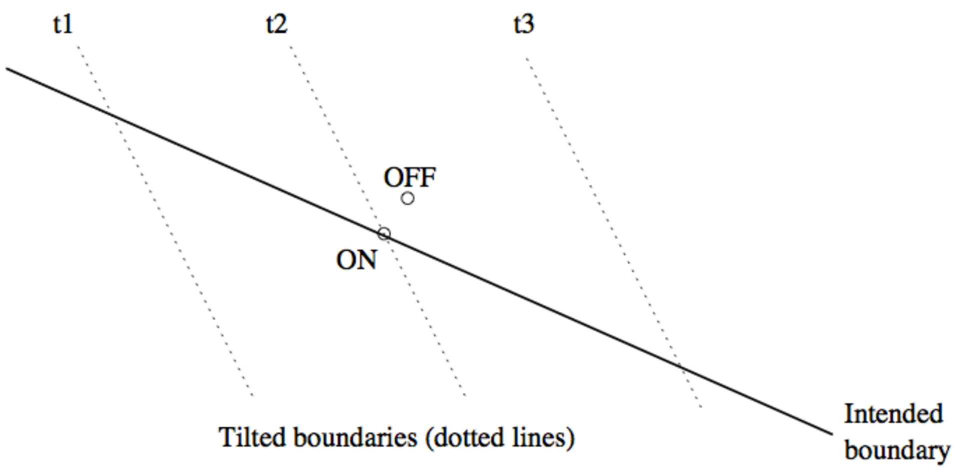
- Motivation: #test-points# without losing much of the problem detection capability.
  - boundary defined by 1 ON 1 OFF

    (n ON points in weak N x 1 form an equivalent class => sampling 1)
  - 2D example: Fig 9.6 (p.139) below.



- Typical errors detected:
    - Closure bug
    - Boundary shift
    - Boundary tilt (not always!)
    - Missing boundary
    - Extra boundary (sometimes)
- Tilting in Fig 9.7, p.140, below

  (miss tilting at ON point, vs. Weak N(cid:2)1)



Other BT Strategies

- Strong vs. weak testing strategies:
    - Weak: 1 set of tests for each boundary
    - Strong: 1 set of tests for each segment
- Why use strong BT strategies?
    - Gap in boundary condition
    - Closure change
    - Coincidental correctness:

      particularly stepwise implementation

    - Code clues: complex, convoluted

    - Use in safety-critical applications
- Nonlinear boundaries: Approximate (e.g., piecewise) strategies often useful.

BT Extensions

- Direct extensions
    - Data structure boundaries.
    - Capacity testing.
    - Loop boundaries (Chapter 11).
- Other extensions
    - Vertex testing:
        - problem with boundary combinations
        - follow after boundary test (1 X 1 etc.)
        - test effective concerns
    - Output domain in special cases
        - similar to backward chaining
        - safety analysis, etc.
- Queuing testing example below.

BT and Queuing

- Queuing description: priority, buffer, etc.

- Priority: time vs. other:
    - time: FIFO/FCFS, LIFO/stack, etc.
    - other/explicit: SJF, priority#, etc.
    - purely random: rare
- Buffer: bounded or unbounded?

- Other information:
    - Pre-emption allowed?
    - Mixture/combination of queues
    - Batch and synchronization

Testing a Single Queue

- Test case design/selection:
    - Conformance to queuing priority.
    - Boundary test
    - Test cases: input + expected output.
    - Combined cases of the above.
- Testing specific boundary conditions:
    - lower bound: 0, 1, 2 (always)
    - server busy/idle at lower bound
    - upper bounds: B, B +/- (bounded Q)

      for bounded queue with bound B

- Other test cases:
    - Typical case: usage-based testing idea.
    - Q unbounded: some capacity testing.

BT Limitations

- Simple processing/defect models:
    - Processing: case-like, general enough?
    - Specification: ambiguous/contradictory.
    - Boundary: likely defect.
    - Vertex: ad hoc logic.
- Limitations
    - Processing model: no loops.
    - Coincidental correctness: common.
    - e-limits, particularly problematic for multi-platform products.
    - OFF point selection for closed domain
        - possible undefined territory,
        - may cause crash or similar problems.
    - Detailed analysis required.