CS 5154

Syntax-based Testing

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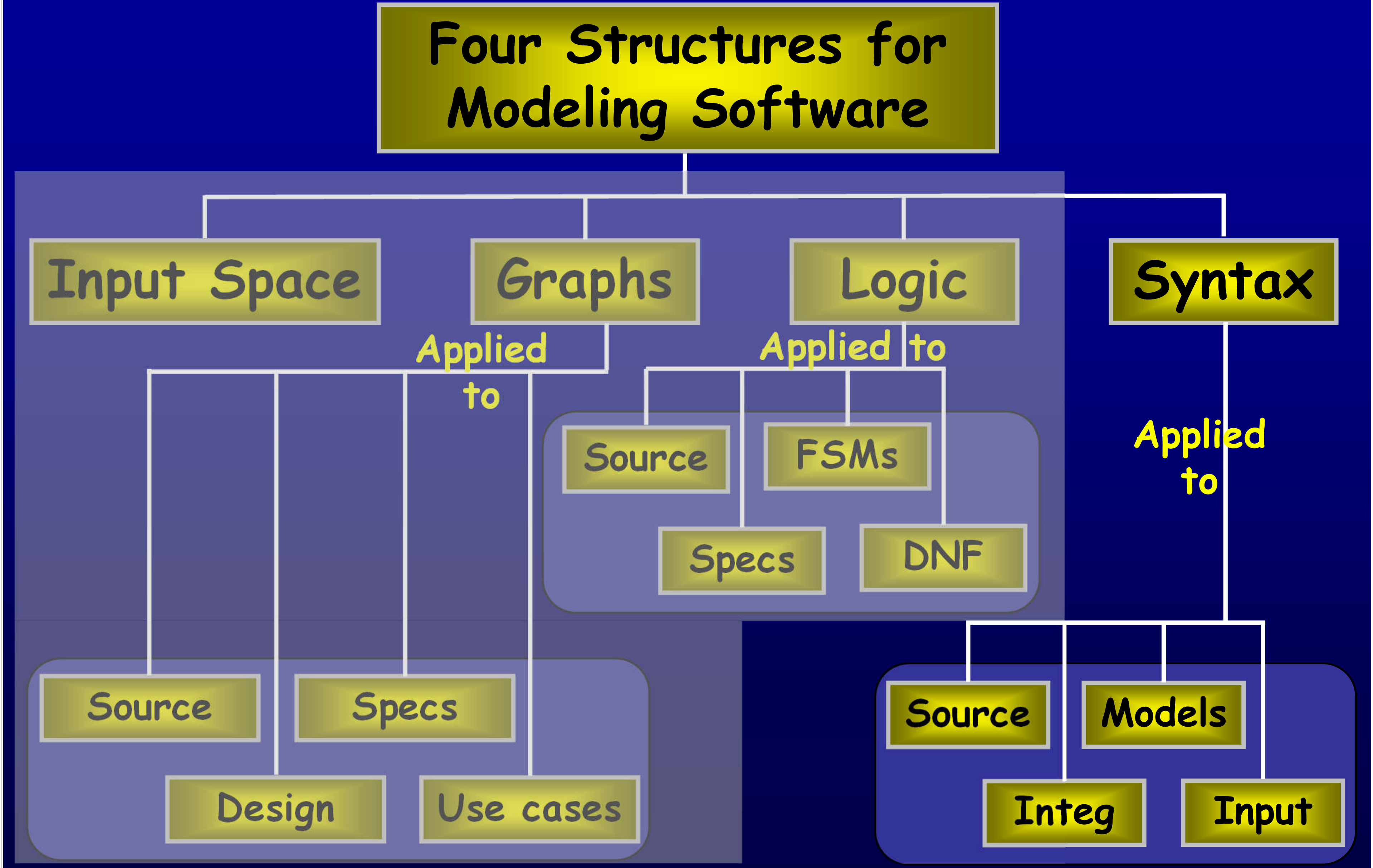
The following are modified versions of the publicly-available slides for Chapter 9 in the Ammann and Offutt Book, “Introduction to Software Testing”
(http://www.cs.gmu.edu/~offutt/softwaretest)

Syntax-based Testing



Four Structures for Modeling Software

Input Space

Graphs

Logic

Syntax

Applied to

Source

Specs

Design

Use cases

Applied to

Source

FSMs

Specs

DNF

Applied to

Source

Models

Integ

Input

Using Syntax to Generate Tests

- Lots of software artifacts follow strict syntax rules
  - Syntax is often expressed as a grammar in a language, e.g., BNF
- Syntactic descriptions can come from many sources
  - Programs, integration elements, design docs, input descriptions
- Syntax-based tests are created with two general goals
  - Cover the syntax in some way
  - Violate the syntax (invalid tests)

Grammar Coverage Criteria

- Software engineers use automata theory in several ways
  - Programming languages defined in BNF
  - Program behavior described as finite state machines
  - Allowable inputs defined by grammars
- A simple regular expression:

(*G s n* | *B t n*)*

'*' is *closure* operator, zero or more occurrences

'|' is *choice*, either one can be used

- Any sequence of "*G s n*" and "*B t n*"
- '*G*' and '*B*' could represent commands, methods, or events
- '*s*', '*t*', and '*n*' can represent arguments, parameters, or values
- '*s*', '*t*', and '*n*' could represent literals or a set of values

Test Cases from the Regex

- Strings satisfying the derivation rules are "*in the grammar*"
- Test: a sequence of strings that satisfy the regex
- Suppose 's', 't' and 'n' are numbers

G 26 08.01.90

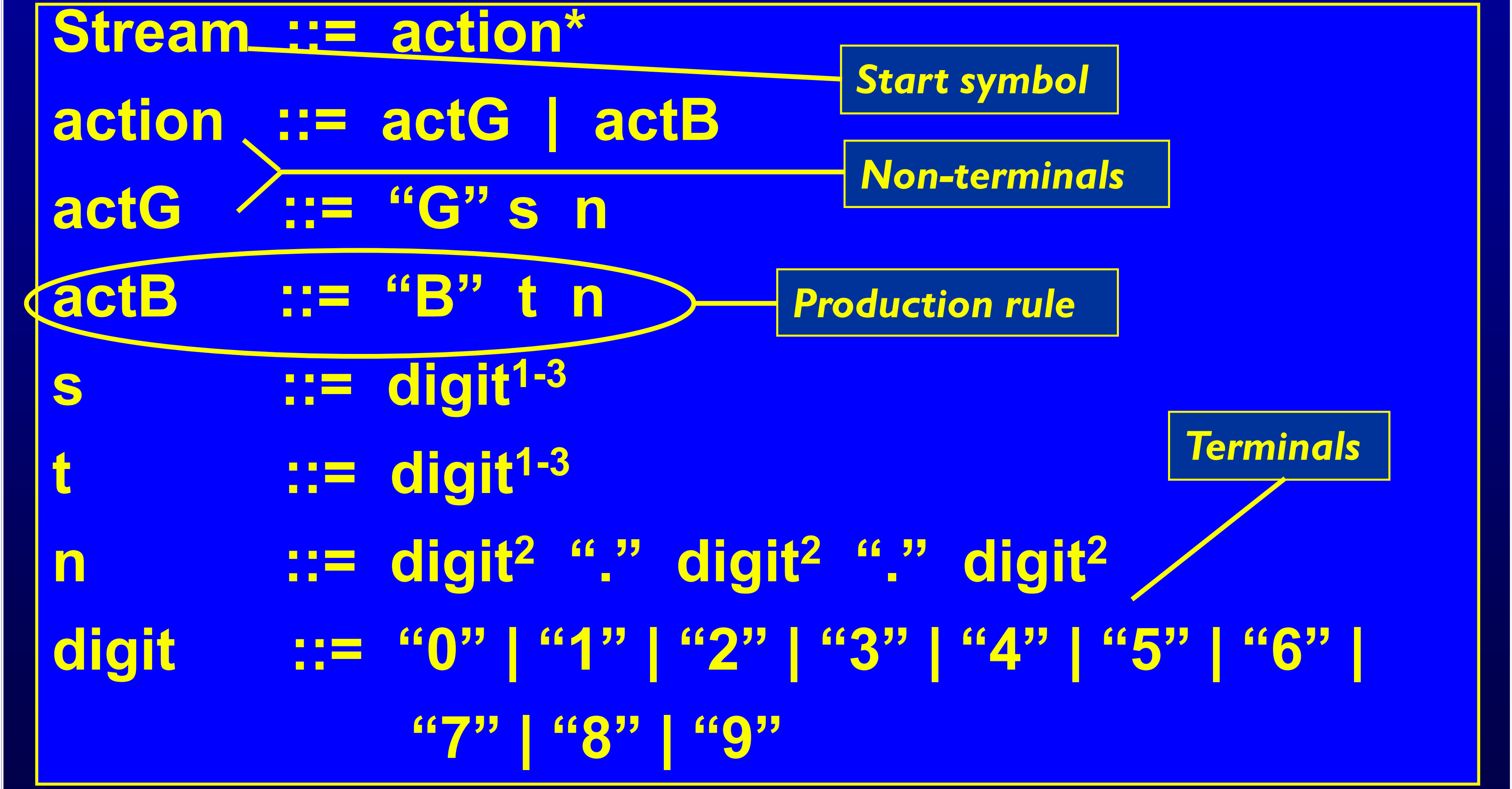
B 22 06.27.94

G 22 11.21.94

B 13 01.09.03

Could be one test with four parts or four separate tests, etc.

BNF Grammars



Stream ::= action*

action ::= actG | actB

actG ::= “G” s n

actB ::= “B” t n

s ::= $\text{digit}^{1\text{-}3}$

t ::= $\text{digit}^{1\text{-}3}$

n ::= digit^{2} “.” digit^{2} “.” digit^{2}

digit ::= “0” | “1” | “2” | “3” | “4” | “5” | “6” | “7” | “8” | “9”

Start symbol

Non-terminals

Production rule

Terminals

Using Grammars

Stream ::= action action *

::= actG action*

::= G s n action*

::= G digit$^{1-3}$ digit^2 . digit^2 . digit^2 action*

::= G digitdigit digitdigit.digitdigit.digitdigit action*

::= G 25 08.01.90 action*

…

- Recognizer : Is a string (or test) in the grammar ?
  - This is called parsing
  - Tools exist to support parsing
  - Programs can use them for input validation
- Generator : Derive strings that are in a given grammar

Grammar-based Coverage Criteria

- The most common and straightforward criteria use every terminal and every production at least once

Terminal Symbol Coverage (TSC) : TR contains each terminal symbol *t* in the grammar *G*.

Production Coverage (PDC) : TR contains each production *p* in the grammar *G*.

- PDC subsumes TSC
- Grammars and graphs are interchangeable
  - PDC is equivalent to EC, TSC is equivalent to NC
- Other graph-based coverage criteria could be defined on grammar
  - But have not

Grammar-based Coverage Criteria (2)

- A related criterion involves deriving all possible strings from the grammar

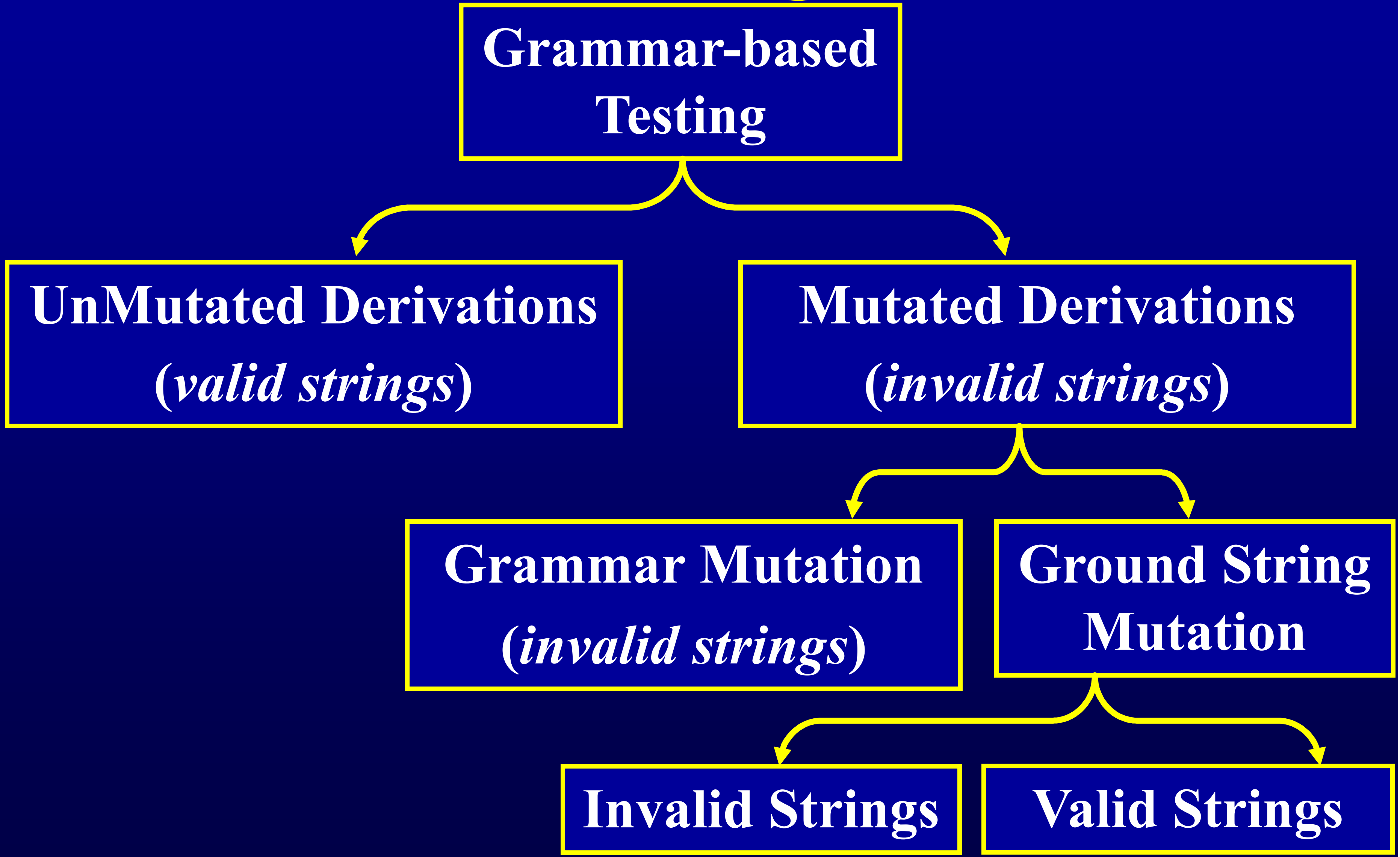
Derivation Coverage (DC) :TR contains every possible string that can be derived from the grammar G.

- DC often requires an impractical number of tests…

Number of tests produced by Grammar-based Criteria

- Number of TSC tests is bound by the number of terminal symbols
  - 13 in the stream grammar
- The number of PDC tests is bound by the number of productions
  - 18 in the stream grammar
- The number of DC tests depends on the details of the grammar
  - 2,000,000,000 in the stream grammar !
- All TSC, PDC and DC tests are in the grammar … how about tests that are NOT in the grammar ?

Mutation as Grammar-Based Testing

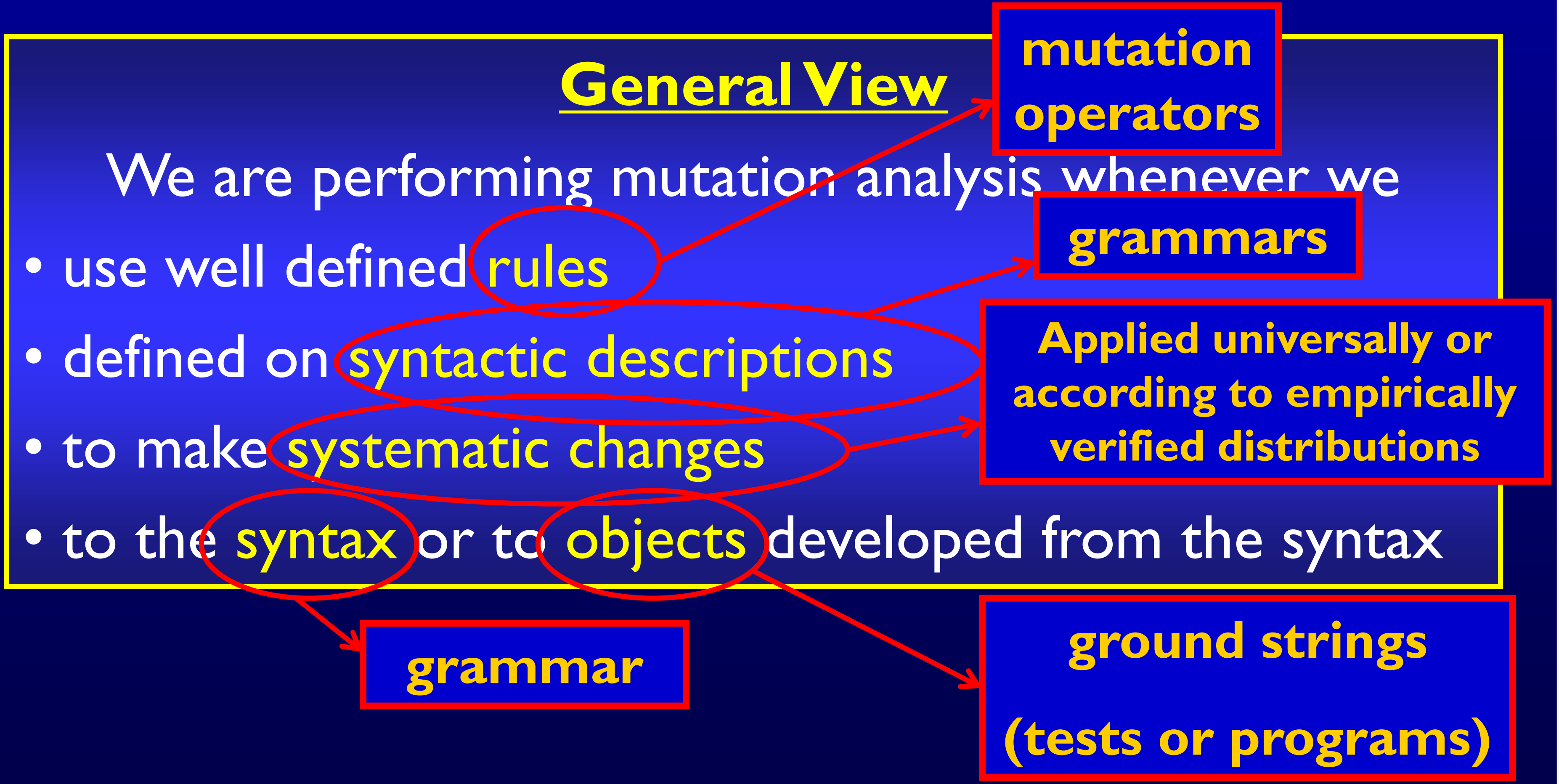


- Grammar-based Testing
  - UnMutated Derivations (*valid strings*)
  - Mutated Derivations (*invalid strings*)
    - Grammar Mutation (*invalid strings*)
    - Ground String Mutation
      - Invalid Strings
      - Valid Strings

Mutation Testing

- Grammars describe both valid and invalid strings
- Both types can be produced as mutants
- A mutant is a variation of a valid string
  - Mutants may be valid or invalid strings
- Mutation is based on "mutation operators" and "ground strings"

What is Mutation ?



General View

We are performing mutation analysis whenever we

- use well defined rules
- defined on syntactic descriptions
- to make systematic changes
- to the syntax or to objects developed from the syntax

mutation operators

grammars

Applied universally or according to empirically verified distributions

grammar

ground strings

(tests or programs)

Mutation Testing

- Ground string: A string in the grammar
  - “ground” is used as an analogy to algebraic ground terms

- Mutation Operator : A rule that specifies syntactic variations of strings generated from a grammar

- Mutant : Result of one application of a mutation operator
  - a string in the grammar or close to being in the grammar

Mutants and Ground Strings

- The key to mutation testing: design of mutation operators
  - Well-designed operators lead to powerful testing
  - Well-designed or not?: change all predicates to true and false
- Sometimes mutants are based on ground strings
- Sometimes they are derived directly from the grammar
  - Ground strings are used for valid tests
  - Invalid tests do not need ground strings

Valid Mutants

Ground Strings	Mutants
G 26 08.01.90	*B 26 08.01.90*
B 22 06.27.94	*B 45 06.27.94*

Invalid Mutants
7 26 08.01.90
B 22 06.27.1

Two Questions About Mutation

- Apply more than one operator at the same time ?
  - Should mutated strings contain multiple mutated elements?
  - Usually not: multiple mutations may interfere with each other
  - Experience with program-based mutation indicates not
  - Recent research is finding exceptions

- Consider all possible applications of a mutation operator ?
  - Necessary with program-based mutation (subsumption)

Mutation Operators are often language-based

- Mutation operators have been defined for many languages
  - Programming languages (*Fortran, Lisp, Ada, C, C++, Java*)
  - Specification languages (*SMV, Z, Object-Z, algebraic specs*)
  - Modeling languages (*Statecharts, activity diagrams*)
  - Input grammars (*XML, SQL, HTML*)

Testing Goal: Killing Mutants

- Hope: Mutants created as valid strings from ground strings should exhibit different behavior from the ground string
- Normally used when grammars are prog. languages, strings are programs, and ground strings are pre-existing programs
- Killing Mutants : Given a mutant $m \in M$ for a derivation D and a test t, t is said to kill m if and only if the output of t on D is different from the output of t on m
- D may be shown as list of productions or as the final string

Syntax-based Coverage Criteria

- Coverage is defined in terms of killing mutants

Mutation Coverage (MC) : For each *m* ∈ *M*, TR contains exactly one requirement, to kill *m*.

- Coverage in mutation equates to killing mutants

- Mutation score : ratio of mutants killed over all mutants

Syntax-based Coverage Criteria

- When creating invalid strings, we just apply the operators
- This results in two simple criteria
- It makes sense to either use every operator once or every production once

Mutation Operator Coverage (MOC) : For each mutation operator, TR contains exactly one requirement, to create a mutated string *m* that is derived using the mutation operator.

Mutation Production Coverage (MPC) : For each mutation operator, TR contains several requirements, to create one mutated string *m* that includes every production that can be mutated by that operator.

Example

Grammar

Stream ::= action*
action ::= actG | actB
actG ::= "G" s n
actB ::= "B" t n
s ::= digit$^{1-3}$
t ::= digit$^{1-3}$
n ::= digit^{2} "." digit^{2} "." digit^{2}
digit ::= "0" | "1" | "2" | "3" | "4" | "5" | "6" | "7" | "8" | "9"

Ground String

G 25 08.01.90
B 21 06.27.94

Mutation Operators

- *Exchange actG and actB*
- *Replace digits with all other digits*

Mutants using MOC

B 25 08.01.90
B 23 06.27.94

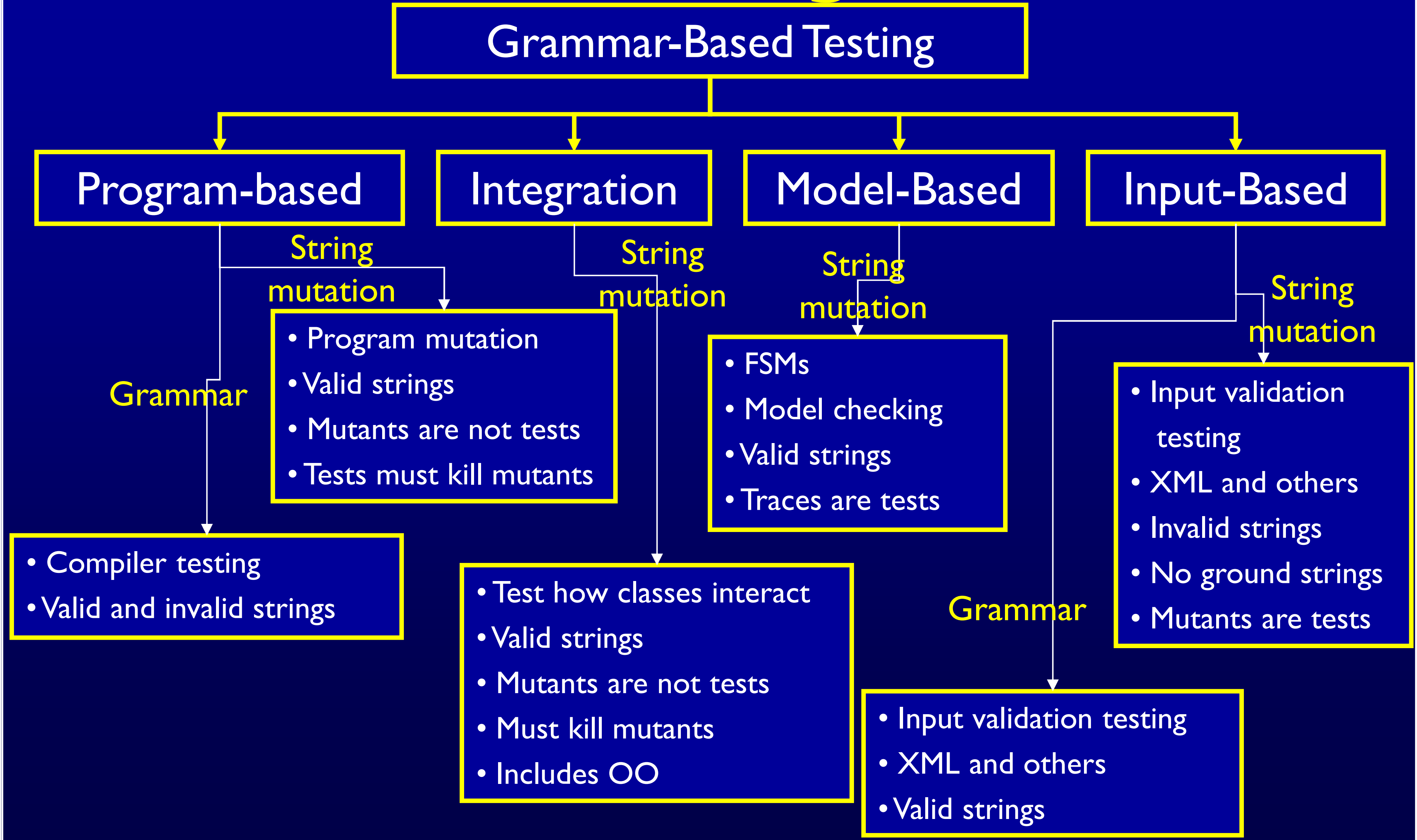
Mutants using MPC

B 25 08.01.90	*G 21 06.27.94*
G 15 08.01.90	*B 22 06.27.94*
G 35 08.01.90	*B 23 06.27.94*
G 45 08.01.90	*B 24 06.27.94*
…	…

Mutation Testing

- Number of test requirements depends on two things
  - The syntax of the artifact being mutated
  - The mutation operators
- Mutation testing is very difficult to apply by hand
- Mutation testing is very effective – sometimes considered the "gold standard" of testing
- Mutation testing is often used to evaluate other criteria
  - How good is your test suite?

Instantiating Grammar-Based Testing



Grammar-Based Testing

Program-based

Integration

Model-Based

Input-Based

String mutation

- Program mutation
- Valid strings
- Mutants are not tests
- Tests must kill mutants

Grammar

- Compiler testing
- Valid and invalid strings

String mutation

- Test how classes interact
- Valid strings
- Mutants are not tests
- Must kill mutants
- Includes OO

String mutation

- FSMs
- Model checking
- Valid strings
- Traces are tests

String mutation

- Input validation testing
- XML and others
- Invalid strings
- No ground strings
- Mutants are tests

Grammar

- Input validation testing
- XML and others
- Valid strings

Next

- Mutation testing (including a demo ☺)

- We should release scores on HW1 and HW2 by end of week
  - Drop deadline?

- Course Project…

Stats about your preferences

- Groups:
  - 20 expressed no preference for teammates
  - 26 expressed preferences for teammates in a consistent way
  - 18 expressed preferences in an inconsistent way
- Reasons for preferences
  - Asia time zone
  - Previous working relationship
  - Personal reasons and friendships
- Options:
  - ~50 chose option 1
  - ~10 chose option 2
  - ~4 chose options 3 and 4

My decision

- Groups:
  - 58 will form groups of 3 (one group will have 4)
  - 6 will form two groups of 3 based on Asia Time Zone
- Reasons for preferences
  - Asia time zone
  - ~~Previous working relationship~~
  - ~~Personal reasons and friendships~~
- Options:
  - ~62 decided on option 1
  - ~2 are still on option 2 but have no one to work with

Next Steps on Course Project

- Project requirements and groups will be released soon

- Spend time meeting your group mates
  - We may dedicate some time in the next class for you to meet
  - We may also have you do HW3 with your project team to facilitate bonding

- Keep working on your course project through the rest of the semester
  - 35% of your course grade
  - Contributions will be clear(er) from the CI server

- We may hold project office hours so you can ask questions