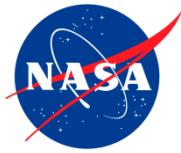

Configuration Testing of Flight Software

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Motivation

- Flight software is configurable
  - Users select values for **configuration options** for the specific missions and platforms
  - Allows code to be reusable, portable, extensible
- Flight software is also mission-critical
  - Needs to be extensively tested and bug free

- Problem: exponential explosion of **configuration space**
  - Tremendously large number of valid configurations

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System Under Test

- **Core Flight Software System (CFS):** a flight software (FSW) environment integrating a reusable core flight executive (cFE)
  - A software product-line developed by the NASA Goddard Space Flight Center (GSFC)
  - Designed to be mission-independent and platform-independent
  - Various missions build flight software on top of CFS
    - E.g. GPM
- CFS is **highly configurable** with hundreds of options
  - E.g. cfe_platform_cfg.h file
    - Options: mem_pool_size, max_pipe_depth, max_event_filters, etc.
  - Easily **billions of configurations** in the configuration space

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Configuration Space

- Every **configuration** should be tested to assure software quality
  - Bugs can be caused by any combinations of option settings, e.g.
    - MAX_PIPE_DEPTH=135 &&
      MAX_EVENT_FILTERS=1200
    - MAX_PIPE_DEPTH=55 &&
      MAX_EVENT_FILTERS=2500 &&
      MEM_POOP_SIZE=500
    - …
- How to ensure every possible combination is bug free?

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Effective Configuration Space

- Many configurations are essentially executing the same system behaviors
  - Code coverage
  - Test case failures
  - System crashes/hangs
- Goal: only test configurations with different behaviors
  - Minimal set of configurations needed to execute all system behaviors
- Practical goal: efficiently approximate the effective configuration space

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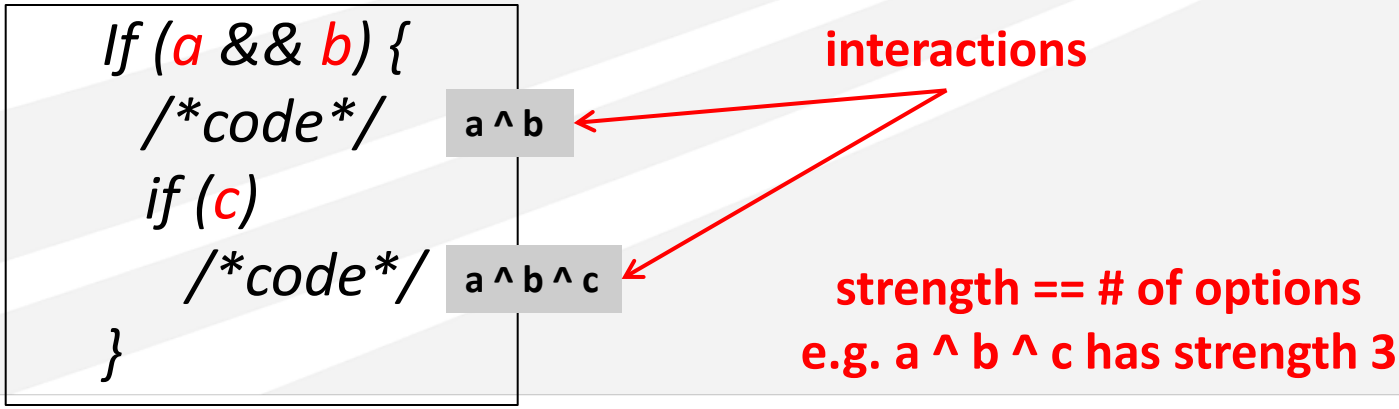
Configuration Interactions

- **Interactions** can tell us about effective configuration space
  - Certain combinations of the options that reveal different system behaviors
  - E.g. complete line coverage



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Observations on Interactions

- Conducted extensive studies on configuration interactions
  - Interactions are rare and have low strength
  - Most behaviors occur at low strength
  - Higher strength interactions tend to include lower strength ones

Reference:

•Elnatan Reisner, Charles Song, Kin-Keung Ma, Jeffrey S.Foster, Adam Porter, "**Using Symbolic Evaluation to Understand Behavior in Configurable Software Systems**," 32nd International Conference on Software Engineering, May 2010

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Interaction Tree Discovery (iTree)

- Iteratively search for the **effective configurations** during testing
  - Generates a small **configuration sample** to observe system behavior
  - Uses **machine learning** to discover potential configuration interactions
  - Narrows the **configuration space** of future samples

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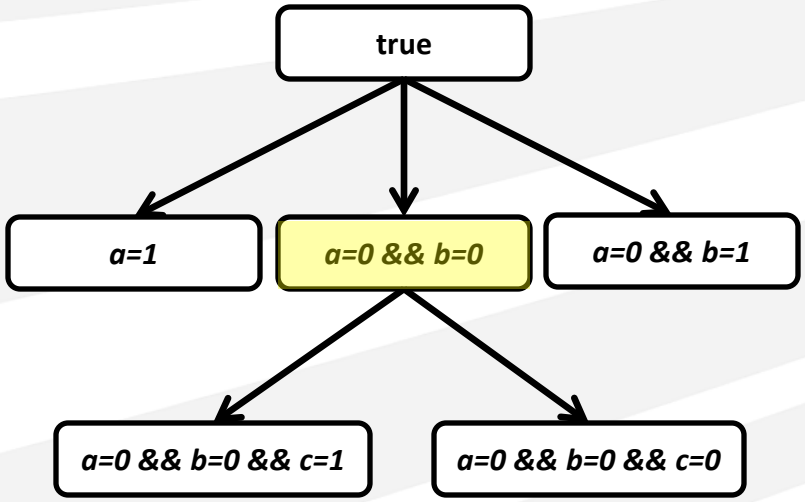
Interaction Tree

- **Internal model** of a system's interactions
  - Hierarchical structure of **interactions**



a	b	c	d
0	**0**	0	0
0	**0**	1	1
0	**0**	0	1
0	**0**	1	0
1	1	1	0

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Previous iTree Results

- Empirically evaluated on several industrial systems
  - vsftpd: secure FTP server shipped w/ RedHat
  - ngIRCd: next generation IRC server
  - MySQL: popular open source database, ~1M LoC

Reference:

•Charles Song, Adam Porter, Jeffrey S.Foster, "**iTree: Efficiently Discovering High-Coverage Configurations Using Interaction Trees**," 34th International Conference on Software Engineering, June 2012

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Effectiveness of iTree

- iTree outperformed existing approaches
  - Achieved higher coverage using 3-4 times fewer configurations
  - Executed more system behaviors sooner in the testing process
  - Automatically determined number of configurations to test
  - Programming language independent

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Intelligence of iTree

- iTree predicts combinations of option settings responsible for the different behaviors
  - E.g. Combination of option settings that caused the system to crash
- No other existing approach can produce such information practically
  - ~95% accurate information at almost no cost during configuration testing process
  - Verified results via static analysis

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Scalability of iTree

- iTree's approximation of the **effective configuration space** can still require a lot of testing efforts
  - Analysis/execution of hundreds of configuration
  - Running test cases for each configuration
- Problem: test execution takes time
  - Need to parallelize configuration testing to be practical

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Automated Distributed Framework

- Integrated iTree with **Skoll DCQA** (distributed continuous quality assurance)
  - Assigns configurations to Skoll for testing
  - Retrieves execution results for analysis
- Fast, robust, and available
  - Designed to support configuration testing
  - Used for numerous research projects at UMD
  - Parallelized iTree configuration testing across 100+ cluster machines

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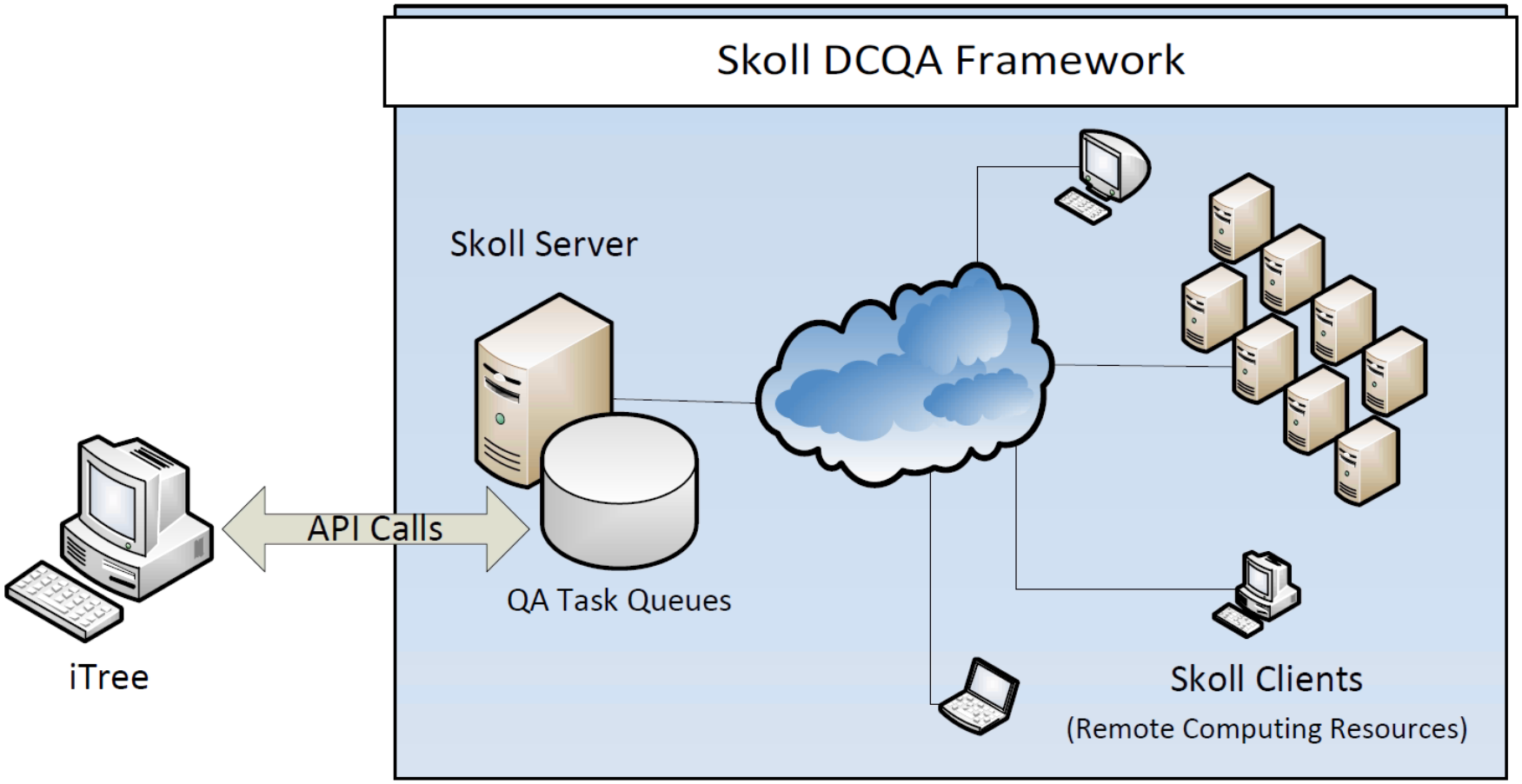
Automated Distributed Framework



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Testing cFE with iTree

- Executed cFE using **stubs** and **unit tests**
- Configuration space model with 40 options
  - Used **min**, **default** and **max** values
- Created automatic configuration file generator
  - E.g. creates valid cfe_platform_cfg.h file
- Parallelized configuration testing on distributed testing framework

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cFE Unit Test Findings

- Found several critical bugs during preliminary configuration testing

Module	Bug	Configuration Option	Option Settings
SB_UT	Core Dumps	CFE_SB_HIGHEST_VALID_MSGID	0x00FF
SB_UT	Hangs	CFE_SB_HIGHEST_VALID_MSGID	0xFFFF
SB_UT	Core Dumps	CFE_SB_MAX_PIPE_DEPTH	<10
EVS_UT	Hangs	CFE_EVS_LOG_ON	Not #defined
EVS_UT	Hangs	CFE_EVS_DEFAULT_TYPE_FLAG	<=0xD
EVS_UT	Core Dumps	CFE_EVS_MAX_EVENT_FILTERS	>16000
ES_UT	Core Dumps	CFE_ES_MEMPOOL_ALIGNED	Not #defined
ES_UT	Core Dumps	CFE_ES_CDS_MAX_NUM_ENTRIES	>16000

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Future Work

- Extending configuration testing on cFE
  - Replace cFE's stubs with actual library calls
  - Increase number configuration options and settings
- Extend iTree to support other program behaviors
  - Passing/failing test cases
  - Performance metrics
- Apply iTree to more NASA flight software!
  - Contact me if you are interested

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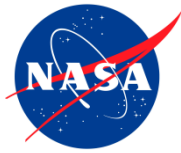

Questions?

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Acronyms

- CDQA: Distributed Continuous Quality Assurance
- cFE: Core Flight Executive
- FSW: Flight Software
- iTree: Interaction Tree
- SUT: System Under Test
- UMD: University of Maryland

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