Automated Test Generation for Flight Software (FSW)

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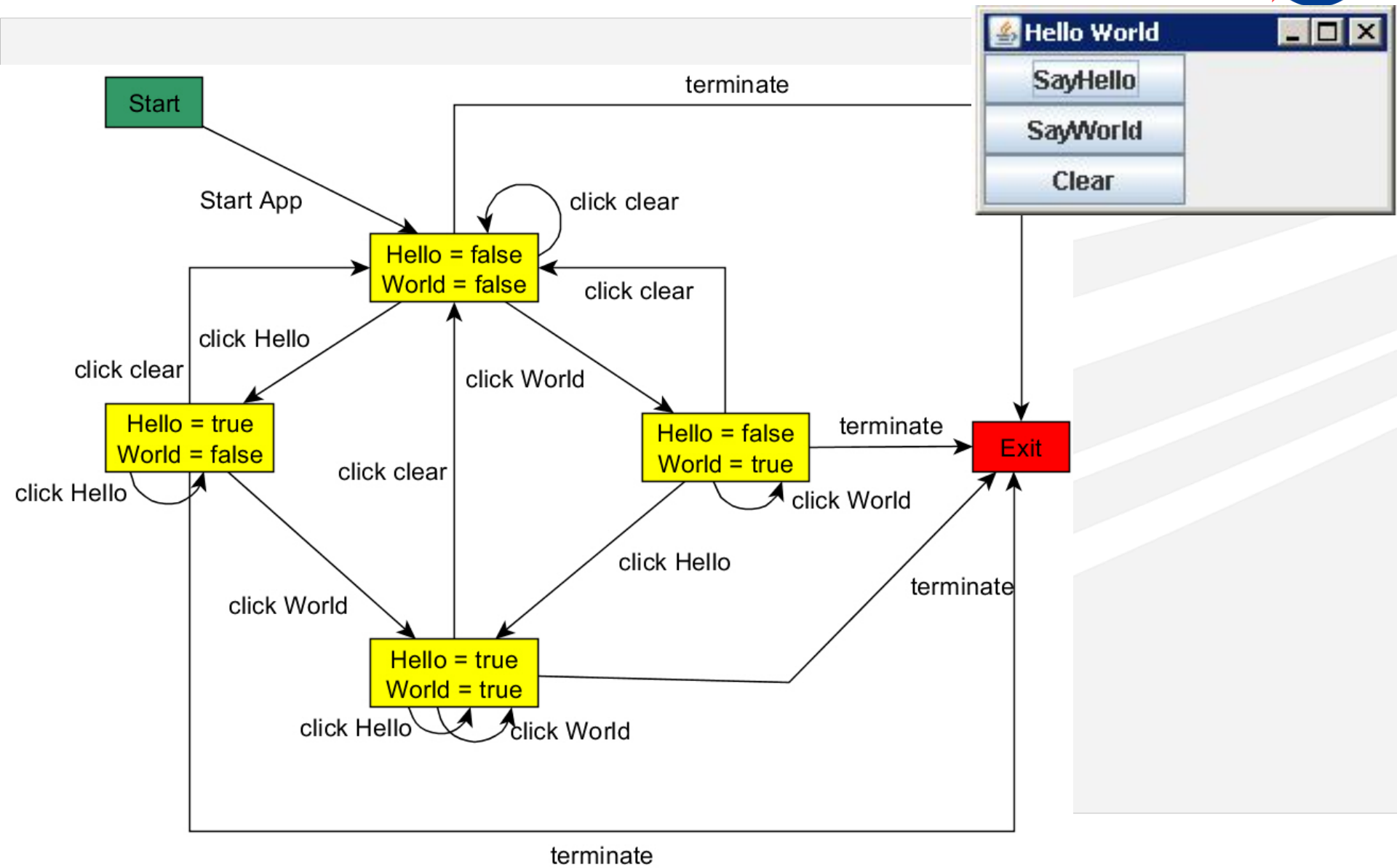
Problems with Current Testing

- Manual testing takes a lot of effort
- Manual testing could miss “corner-cases”
- Test cases difficult to maintain and reuse on multiple environments
- Tests are technical, typically not domain oriented
  - and thus difficult to understand for non-technical stakeholders

Model based testing (MBT)

- Solution: Generate Test Cases using MBT!
  - We incrementally model the behavior of the software to be tested
    - Good and “Evil” usages
    - Expected results are embedded in the model
  - Based on the model, the test generator automatically generates test cases
  - Any type of test cases can be generated
    - Junit, Xunit, soapUI, Selenium, CuTest, etc.
- Extra benefits
  - We have a very visual representation of the system
  - Test cases are domain oriented and easier to understand for non-technical stakeholders
  - Documentation of behavior

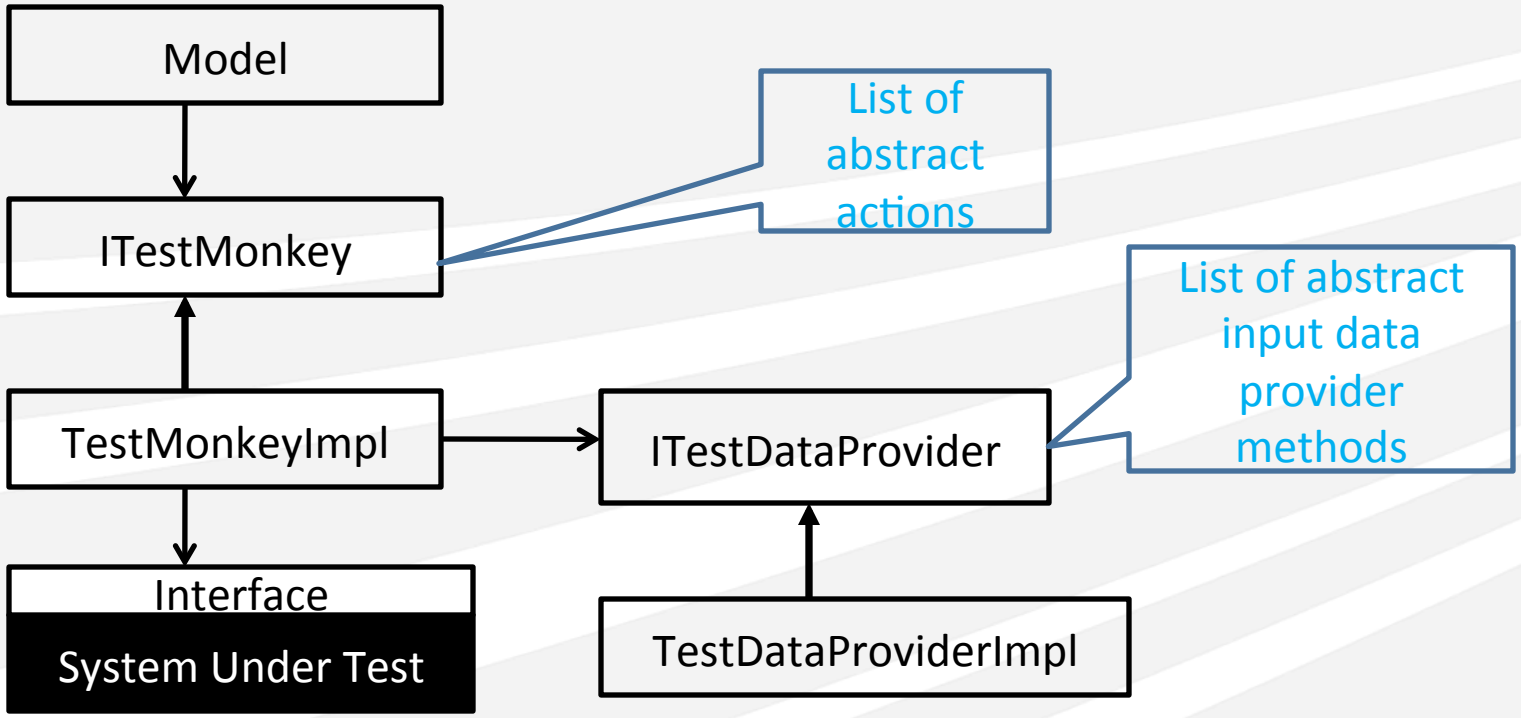
Hello World to MBT



Terminology

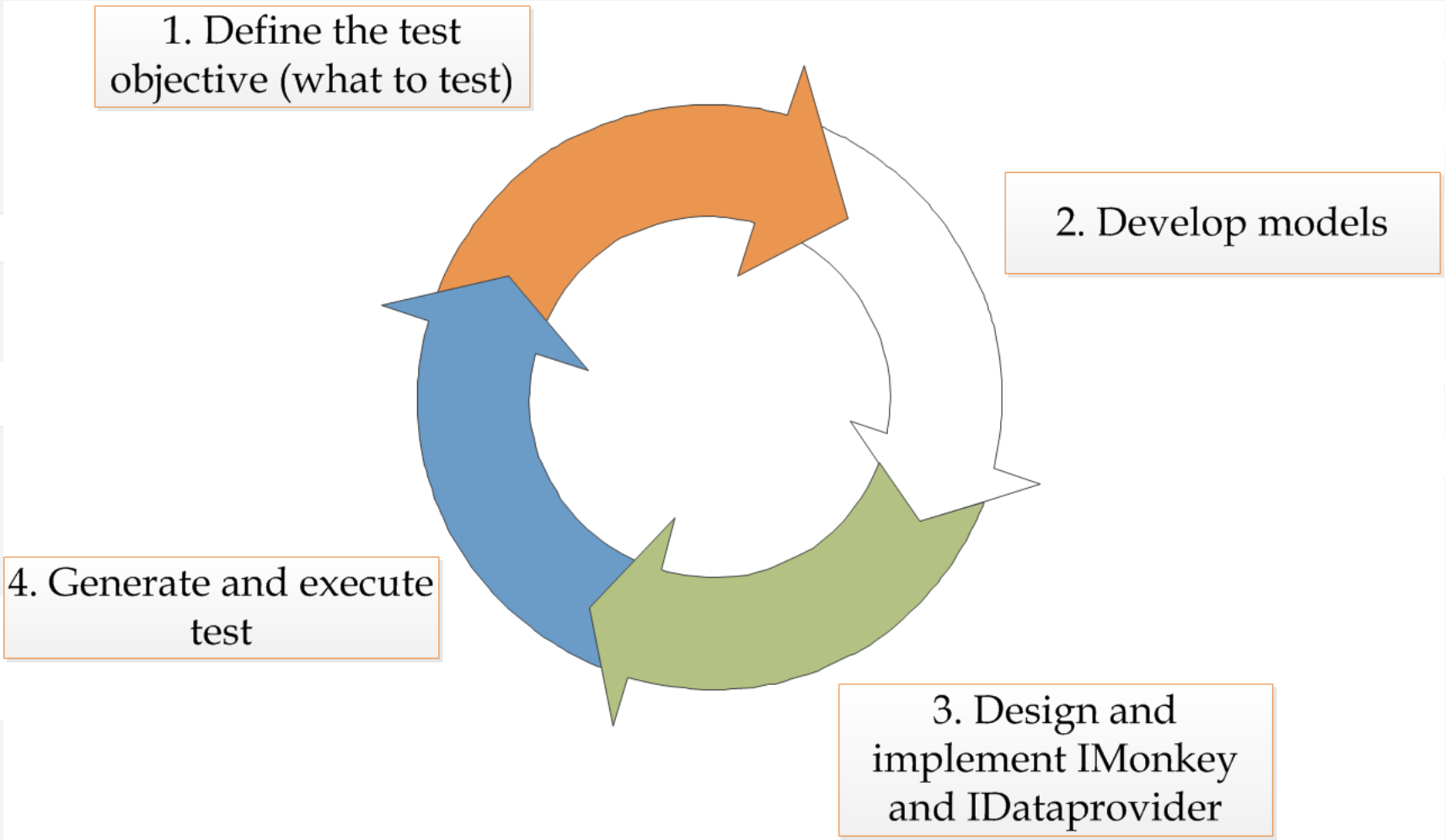
- Nodes of the model are called states
- Edges of the model are called transitions
- Each test case is a path from the start state to the exit state
- A random test is generated using a random walk from the start state to the exit state
- A test suite is a collection of test cases

Architecture of MBT



- Model is agnostic to the test execution technology
- ITestMonkey interface hides the test execution framework
- TestMonkeyImpl uses interfaces of the test execution framework

Workflow



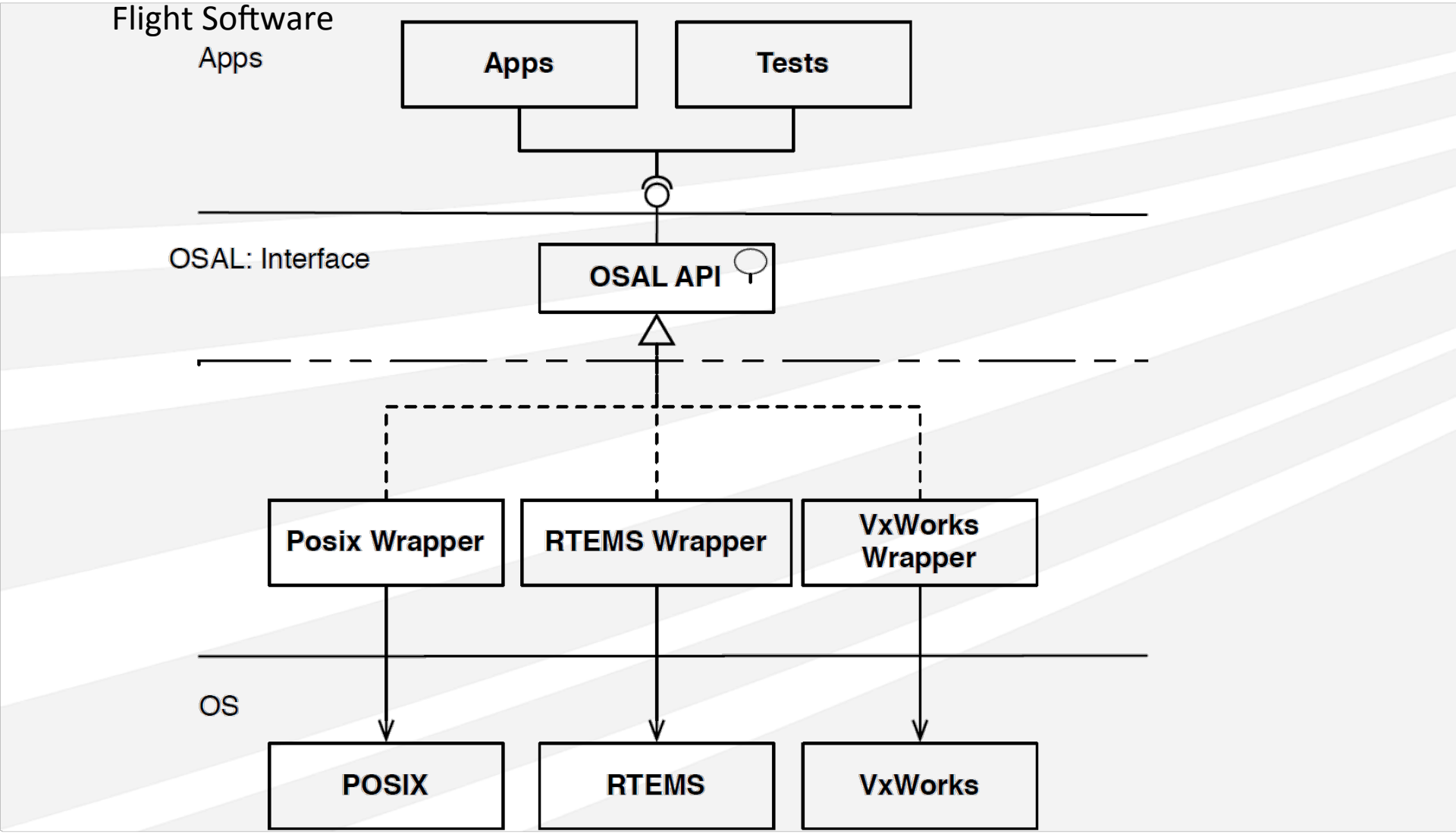
Flight Software Under Test

- **O**perating **S**ystem **A**bstraction **L**ayer (OSAL)
- Isolates flight software from operating systems and hardware
- Implementations for the real time systems RTEMS and VxWorks and posix compliant non-real time systems
- Used for mission critical embedded systems
- Provides support for file-system, tasks, queues, semaphores, interrupts, hardware abstraction, I/O ports and exception handling

NASA OSAL

- Why is it important that OSAL be bug free?
  - Flight software is mission critical and needs to be of very high quality
  - OSAL is the foundation of the core Flight Executive (cFE)
  - OSAL is used in many NASA missions, e.g. the Lunar Renaissance Orbit
  - If OSAL has issues, it might result in catastrophic failure

NASA OSAL – Architecture



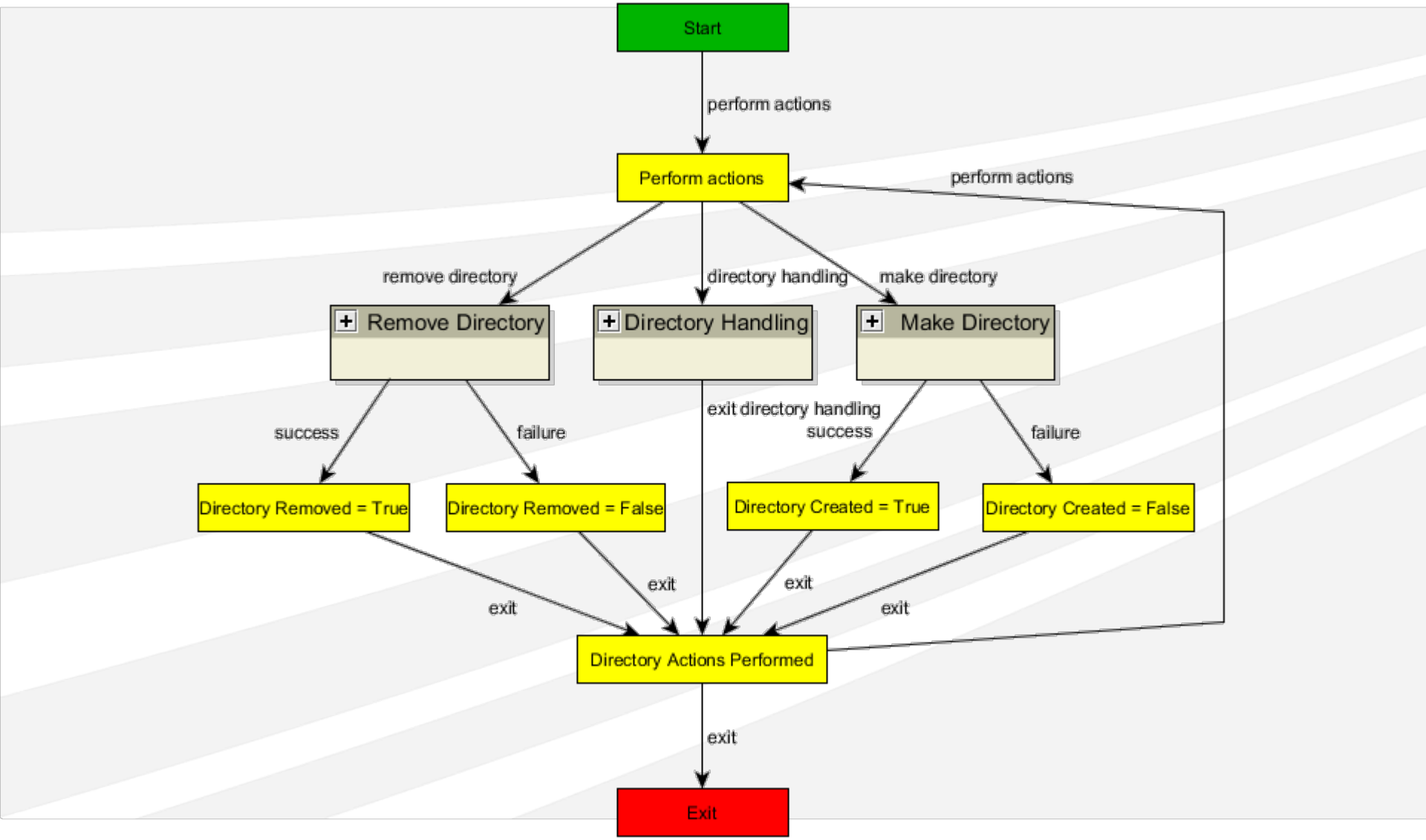
Applying MBT on OSAL

- Model captures OSAL's <u>expected behavior</u>
- Test monkey has abstract instructions e.g. "CreateFileValid", "CreateFileInvalid"
- We created and used a dynamic data provider
  - Generates file and folder names
  - Generates content for files

Applying MBT on OSAL ...

- OSAL‘s file system API‘s were modeled
- Several test cases in C were automatically generated
  - We used the open source CuTest test execution framework

Example of a OSAL model

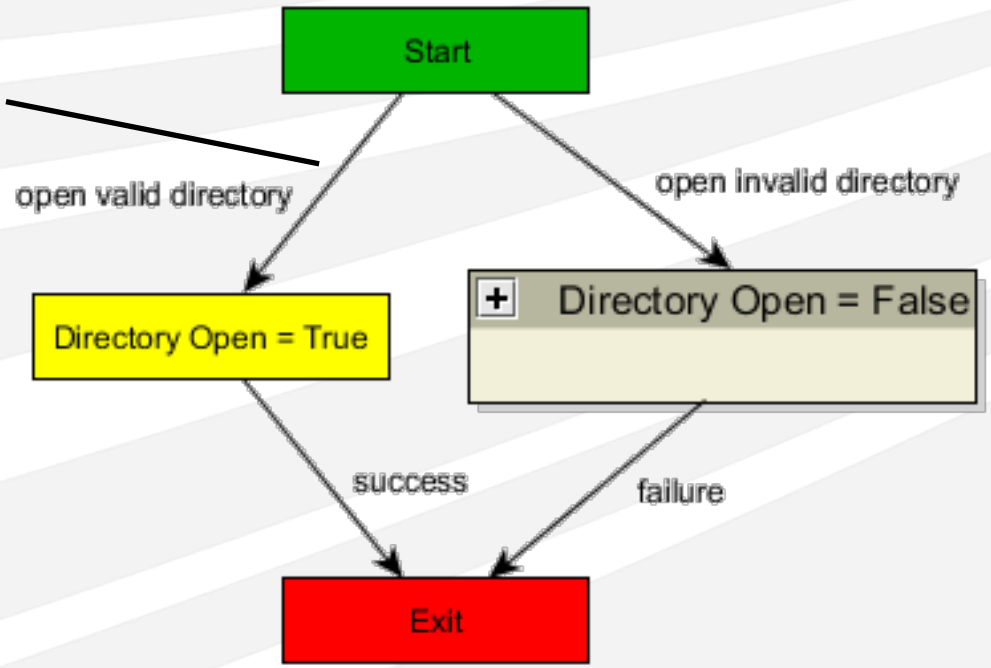


API spec of make directory

```
/*-----------------------------------------------------------------------------
   Name: OS_mkdir

   Purpose: makes a directory specified by path.

   Returns: OS_FS_ERR_INVALID_POINTER if path is NULL
            OS_FS_ERR_PATH_TOO_LONG if the path is too long to be stored locally
            OS_FS_ERR_PATH_INVALID if path cannot be parsed
            OS_FS_ERROR if the OS call fails
            OS_FS_SUCCESS if success

   Note: The access parameter is currently unused.
-----------------------------------------------------------------------------*/

int32 OS_mkdir (const char *path, uint32 access);
```

Sub-model of make directory

```
pointer = openDirectoryValid();
CuAssertTrue(tc,pointer != NULL);
```



Sample generated Test in CuTest

```
void Testosal_Filesystem_min_2(CuTest* tc)
 {
    status = makeFilesystemValid();
    CuAssertIntEquals_Msg(tc,"Filesystem could not be created",
                                    OS_FS_SUCCESS, status);

    status = mountFilesystemValid();
    CuAssertIntEquals_Msg(tc,"Filesystem could not be mounted",
                                    OS_FS_SUCCESS, status);

   pointer = openDirectoryValid();
   CuAssertTrue(tc, pointer != NULL);
   …
   status = removeFilesystemValid();
   CuAssertIntEquals_Msg(tc,"Filesystem could not be removed”, status);
}
```

Issues found using MBT

- OSAL is a high-quality product (only a few issues detected!)
- Issues found when running model based tests on the Posix implementation of OSAL:
- File-descriptors after removing file-system:
  - After somewhat long tests we would run out of file-descriptors
  - This would even happen with a newly created file-system
  - Cause: OSAL does not remove file-descriptors when the file-system is removed
- Wrong error codes returned and unimplemented features:

Test scenario	Error message	Expected	Actual
checkFileSystemNullName()	Expected 'invalid pointer' error	OS_FS_ERR_INVALID_POINTER	OS_FS_UNIMPLEMENTED
checkFileSystemOsCallFails()	Expected 'filesystem' error	OS_FS_ERROR	OS_FS_UNIMPLEMENTED
checkFilesystemValid()	Filesystem Not Checked	OS_FS_SUCCESS	OS_FS_UNIMPLEMENTED
copyFileLongSourceFilename()	Filesystem error code expected	OS_FS_ERROR	OS_FS_ERR_NAME_TOO_LONG
copyFileNonExistingSourceFile()	Filesystem error code expected	OS_FS_ERROR	OS_FS_SUCCESS
renameFileLongSourceFilename()	Filesystem error code expected	OS_FS_ERROR	OS_FS_ERR_NAME_TOO_LONG

MBT – some limitations

- Modeling requires specification of SUT
- Developers are typically not used to modeling
- Difficult to document individual test cases
  - Note: Models summarize all test cases
  - Some customers require document of each test case

Summary and Future Work

- MBT works for API-based testing!
- Some detected issues are serious (e.g., running out of file descriptors)
- MBT requires manual work for
  - constructing models
  - monkey and data provider implementations
  - maintenance of above artifacts
- However, test cases are automatically generated
- Future:
  - Evaluating it on requirements of cFE/CFS
  - ROI estimation

Acknowledgement

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- Thank you!

Acronyms

- API: Application Program Interface
- cFE: Core Flight Executive
- CFR: Code of Federal Regulations
- CFS: Core Flight Software
- FSW: Flight Software
- MBT: Model-based Testing
- OSAL: Operating System Abstraction Layer
- ROI: Return on Investment
- SUT: System Under Test