

Toward “Continuous SAGE”

**How to Interrupt and Migrate
Dynamic Test Generation**

Mehdi Bouaziz’s End-of-Internship talk

Joint work with Ella Bounimova (mentor),
Patrice Godefroid (MSR), David Molnar (MSR)
and Eric Jarvi (Office)

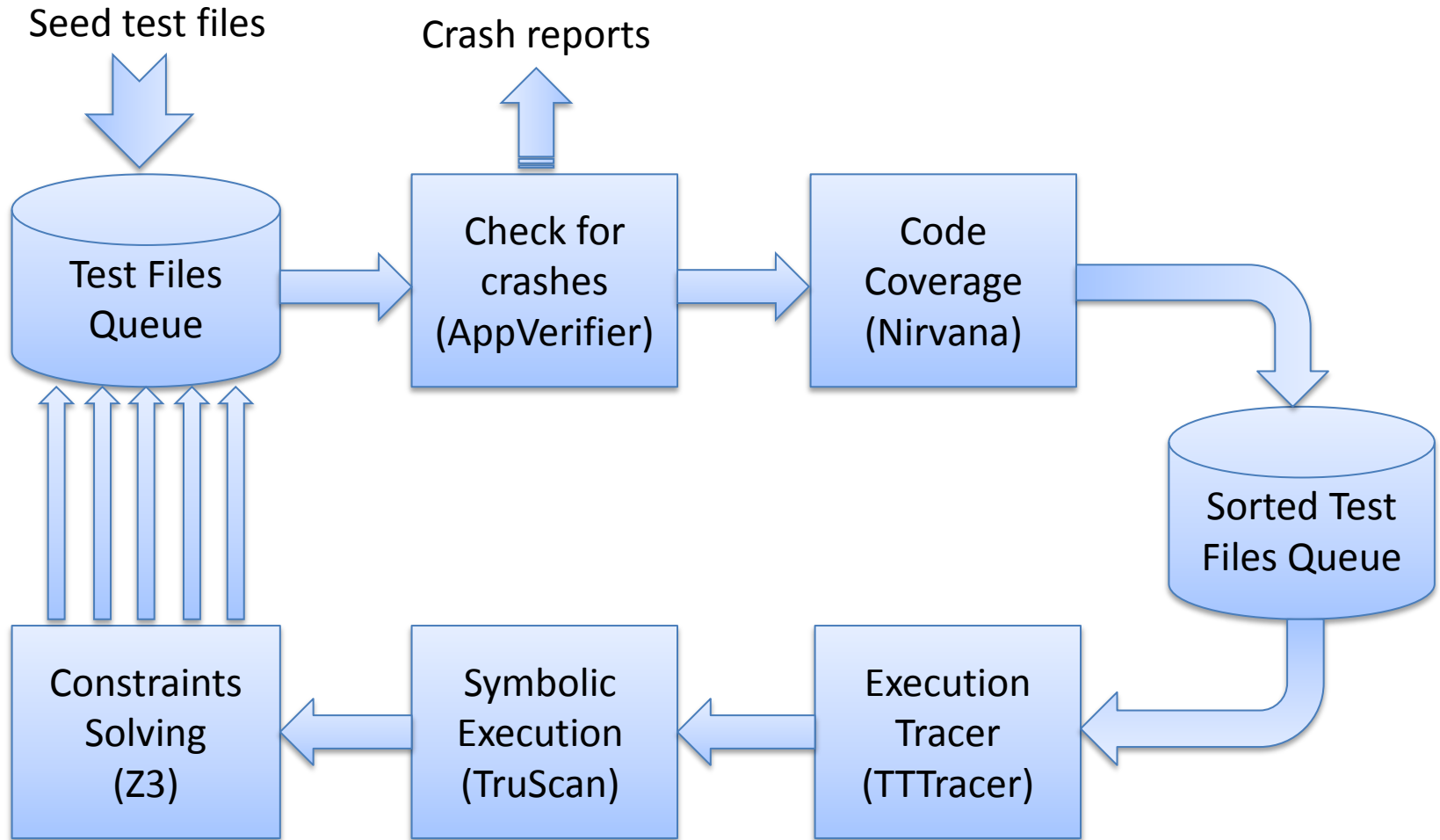
Security is Critical to Microsoft

- Software security bugs can be **very expensive**:
 - Cost of each MS Security Bulletin: \$Millions [MS Treasury Group]
 - Cost due to worms: \$Billions
 - Impact a billion computers worldwide
- Many security exploits are initiated via files or packets
 - Windows and Office include parsers for hundreds of file formats
- Security testing: *hunting for million-dollar bugs*
 - Write A/V (always exploitable), Read A/V (sometimes exploitable), NULL-pointer dereference, division-by-zero (harder to exploit but still DOS attacks), etc.

Whitebox Fuzzing

- Blackbox fuzzing and static analysis miss security bugs
- Idea: mix fuzz testing with **dynamic test generation**:
 - **Symbolic execution** to collect constraints on inputs
 - Negate constraints, **solve new constraints** to generate new test files
 - Repeat → “systematic dynamic test generation”

SAGE Architecture



SAGE Results on Windows

- Run on hundreds of applications.
- Dedicated fuzzing lab with 100s machines (unique organization in Microsoft)
- Running several weeks 24/7 for each Windows 7 and 8 milestone
- A third of all Windows 7 bugs discovered by file-fuzzing (mostly missed by blackbox fuzzing and static analysis)

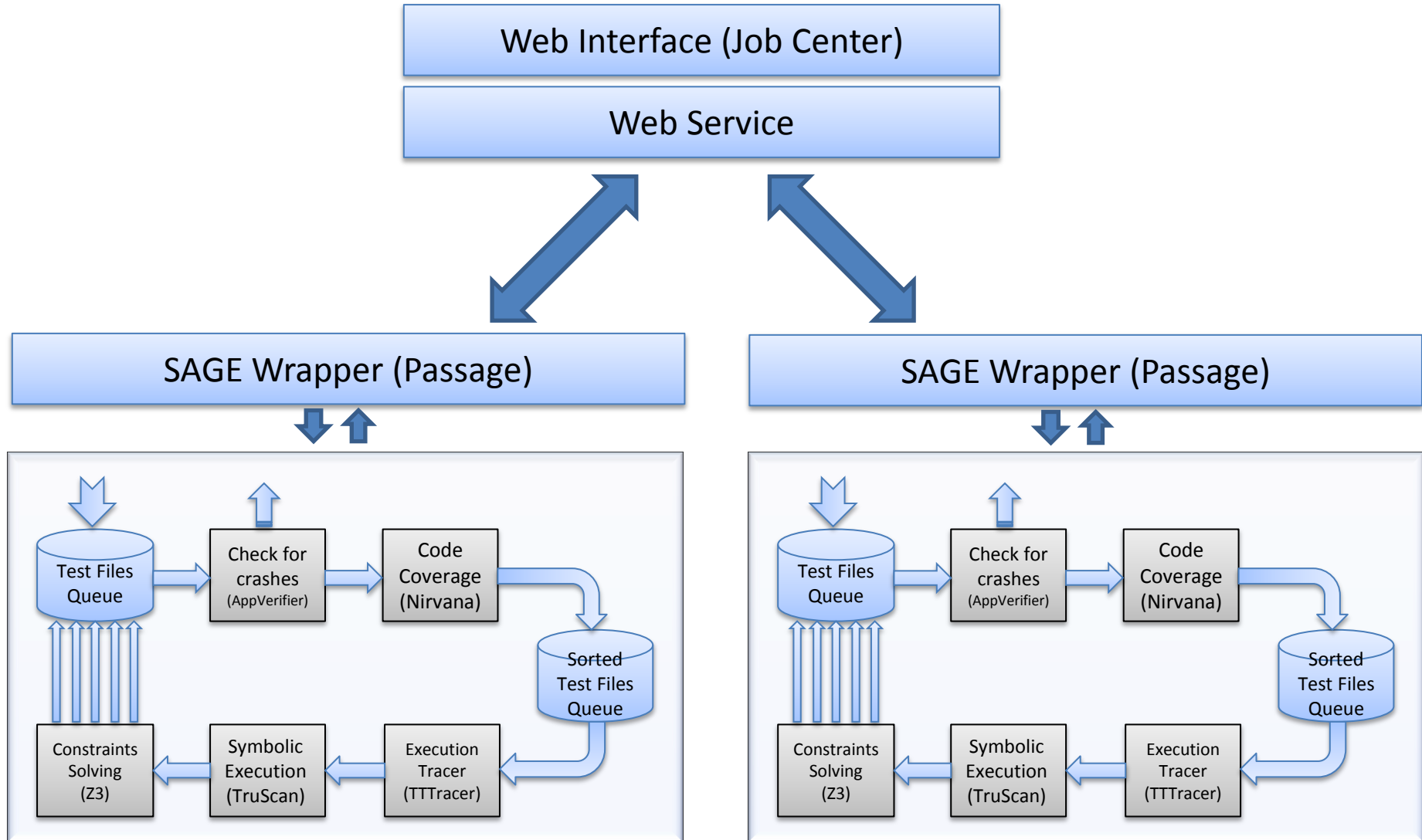
Fuzzing Office with SAGE

- Tens of parsers
- 3 different security testing architectures:
 - 30 dedicated VMs on 2 servers
 - Big Button Lab (hundreds of machines for 6-hour time slots every week)
 - Distributed File Fuzzing (DFF)

Why do we need to redesign SAGE?

- SAGE couldn't tolerate interruption
 - Machine failure
 - Power outages
 - Security patches
- SAGE couldn't be migrated from machine to machine
- SAGE couldn't use multiple machines on a single test job
- SAGE runs out of disk space often
- Too much manual effort to control and deploy SAGE for Office

Redesigned SAGE



SAGE Job Center

SAGE Job Center - Windows Internet Explorer

http://sagan:8090/

SAGE Job Center

SAGE Job Center

Welcome to SAGE Job Center

To learn more about SAGE, visit [SAGE.wiki](#).

[Refresh](#) [New job](#)

102 project-mpp14 (cont. #1) 7/2/2011 12:09:15 AM 7/2/2011 9:07:20 AM ☒ d:\sage\jobs\project-mpp14_1 Success Failure REDMOND\dozer on TWC-SAGEBB-0108 (U) Edit Copy Job Delete Reset Status

103 word-doc-no-nfib (cont. #1) 7/2/2011 7:36:37 AM 7/2/2011 1:41:59 PM ☒ d:\sage\jobs\word-doc-no-nfib_1 Success Success (Continuation Created) REDMOND\dozer on EJVMM0002 (U) Edit Copy Job Delete Reset Status

104 word-doc-no-nfib (cont. #2) 7/2/2011 1:41:59 PM 7/2/2011 7:42:39 PM ☒ d:\sage\jobs\word-doc-no-nfib_2 Success Success (Continuation Created) REDMOND\dozer on EJVMM0002 (U) Edit Copy Job Delete Reset Status

105 word-doc-no-nfib (cont. #3) 7/2/2011 7:42:39 PM 7/3/2011 1:44:20 AM ☒ d:\sage\jobs\word-doc-no-nfib_3 Success Success (Continuation Created) REDMOND\dozer on EJVMM0002 (U) Edit Copy Job Delete Reset Status

106 word-doc-word2003 (cont. #1) 7/2/2011 8:00:47 PM 7/3/2011 2:07:32 AM ☒ d:\sage\jobs\word-doc-word2003_1 Success Success (Continuation Created) REDMOND\dozer on EJVMM-0201 (U) Edit Copy Job Delete Reset Status

107 word-doc-no-nfib (cont. #4) 7/3/2011 1:44:20 AM 7/3/2011 7:20:47 PM ☐ d:\sage\jobs\word-doc-no-nfib_4 Success Success (User Hit Ctrl C) REDMOND\dozer on EJVMM0002 (U) Edit Copy Job Delete Reset Status

108 word-doc-word2003 (cont. #2) 7/3/2011 2:07:32 AM 7/3/2011 8:21:29 PM ☒ d:\sage\jobs\word-doc-word2003_2 Success Success (Continuation Created) REDMOND\dozer on EJVMM-0201 (U) Edit Copy Job Delete Reset Status

109 word-doc-word2003 (cont. #3) 7/3/2011 8:21:29 PM 7/3/2011 8:56:13 PM ☐ d:\sage\jobs\word-doc-word2003_3 Undone Undone REDMOND\dozer on EJVMM-0201 (U) Edit Copy Job Delete Reset Status

1 2 3 4 5

[Refresh](#) [New job](#)

Job details

JobID 60

Title project-mpp14

Creation 5/25/2011 10:08:40 AM

Last Update 7/1/2011 7:26:02 PM

Enabled ☒

Install Directory d:\sage\jobs\project-mpp14

Seed File seeds

Config File parallel.ini

Extra Arguments /logfilesage.out

Sage Path

Install Status Success Reset

Run Status Success (Continuation Created) Reset

Assigned To REDMOND\dozer on TWC-SAGEBB-0108 Unassign

SaganRunID af51e4d7-1dd4-4b3d-9054-1b40cb25fc6f

Backup Directory \\officet4\sagestorage\$\project-mpp14

Files to Copy

Source

Destination

\\twc-sceng-01

jobs\queued\project-mpp14*

Current status

Last Heartbeat 7/2/2011 12:09:15 AM

Machine Time 7/2/2011 12:09:19 AM

Deadline 7/2/2011 12:08:56 AM

Last Assignment

Last StartTime 7/1/2011 9:05:01 PM

Last EndTime 7/2/2011 12:09:19 AM

MaxRunTime 55min

Estimated time sum 1min 58s 894ms

Estimated needed time 7h 26min 19s 27ms

Heartbeat frequency 8s

Will create continuation True

Task	QueueSize	AvgDuration	Running	Processed	Priorities
TestfileTask	0	12s 504ms	0	0	
CoverageTask	10	10s 808ms	1	0	0
TracerTask	0	2min 3s 639ms	0	0	
TruscanTask	0	38min 20s 3ms	0	0	
CleanupTask	0	5ms	0	0	

[Refresh](#)

Actions

Reset Status Stop Now

MaxRunTime Set

HeartbeatFreq Set

Loop control

AssignJobs: On / Off

ReadQueue: On / Off

ForceStayInLoop: On / Off / Auto

Stats: On / Off

CreateContinuation: On / Off / Auto

Move queue

ALL TASKS

Max number:

Max percentage:

Max estimated time:

Max size:

☐ if MaxRunTime will be exceeded

Destination: \\officet4\sagestorage\$\

[Move queue](#) [Copy queue](#) [Delete queue](#)

Passage log messages

Clean log messages All Before last start

Debug messages 497

Error messages 1

7/2/2011 12:09:19 AM Continuation job added successfully: #102

7/2/2011 12:09:19 AM Run exited with code 1

7/2/2011 12:07:46 AM MoveQueue: 10 directories moved, Success

7/2/2011 12:07:17 AM MoveQueue: 18 directories moved, Success

7/2/2011 12:06:45 AM MoveQueue: 0 directory moved, Success

7/2/2011 12:06:16 AM MoveQueue: 0 directory moved, Success

7/2/2011 12:05:46 AM MoveQueue: 0 directory moved, Success

7/2/2011 12:05:17 AM MoveQueue: 0 directory moved, Success

7/2/2011 12:04:48 AM MoveQueue: 0 directory moved, Success

7/2/2011 12:04:19 AM MoveQueue: 0 directory moved, Success

7/2/2011 12:03:50 AM MoveQueue: 0 directory moved, Success

7/2/2011 12:03:21 AM MoveQueue: 0 directory

Done

Local intranet | Protected Mode: Off

95%

SAGE must not fail with “low on disk”

Windows Milestone	Failed with low on disk	% of all runs
M1	7	1.7%
M2	24	8.8%

- SAGE is very disk-consuming (hundreds of GB per week)

→ Solution: New Urgent Cleanup Option

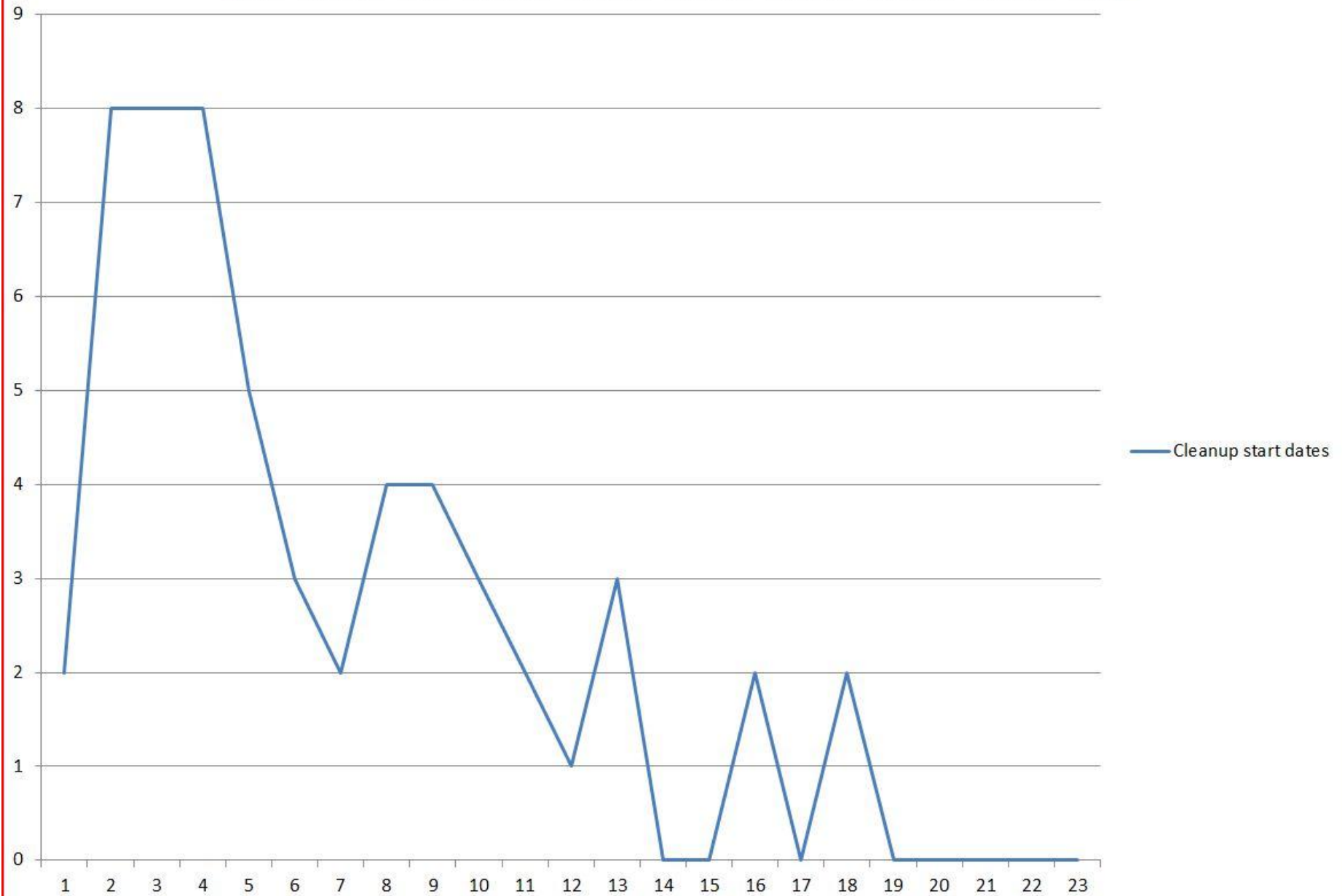
SAGE must not fail with “low on disk”

Windows Milestone	Failed with low on disk	% of all runs
M1	7	1.7%
M2	24	8.8%
M3	0	0%

Windows Milestone	Number of runs with Urgent Cleanup triggered	%
M3	57	16% of all runs
M3 (runs that found crashes)	37	40% of the runs with crashes

- 2.1 million files were cleaned during M3
- UrgentCleanup was triggered on 40% of the crash-finding runs (1.5 million files cleaned)

Urgent Cleanup Start Days for 57 SAGE runs in Windows M3



What if someone “unplugs” the machine?

- The current state is lost, the runs cannot be resumed
- It happens! (Power cut, Security patches)
- DFF machines has to be given back quickly to the user

→ Solution:
Persistent Queue
Option

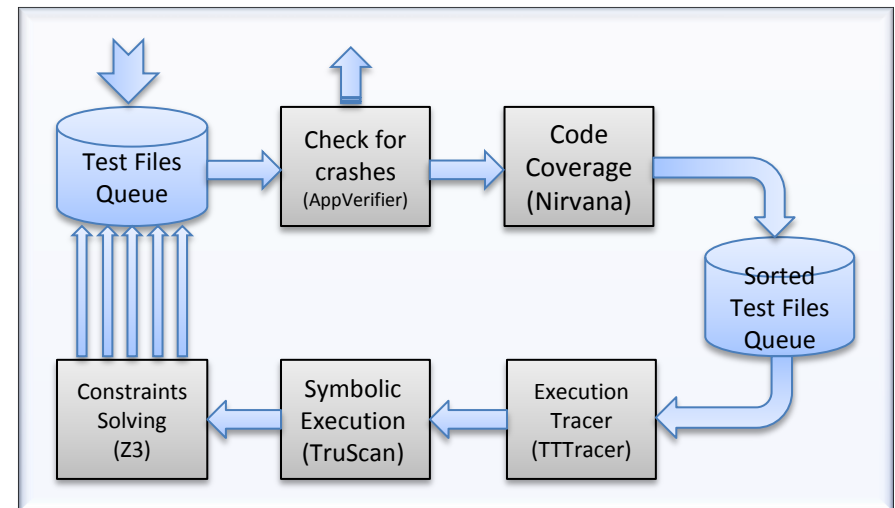


Jobs Migration

- Machines can be reclaimed (and they will)

Solution: migrate runs throughout the run from machine to machine

- Migrate low-priority tasks first
- Use statistics on the run to move only what is needed



SAGE Job Center

SAGE Job Center - Windows Internet Explorer

http://sagan:8090/

Steamboat Rock, wa

SAGE Job Center

Welcome to SAGE Job Center

To learn more about SAGE, visit [SAGE.wiki](#).

[Refresh](#) [New job](#)

JobID	Title	Creation	LastUpdate	LastHeartbeat	Enabled	InstallDirectory	SeedFile	StatusInstall	StatusRun	Assigned	Edition
89	excel-xls-biff2 (cont. #2)	7/1/2011 8:34:49 PM		7/1/2011 8:35:17 PM	<input checked="" type="checkbox"/>	d:\sage\jobs\excel-xls-biff2_2		Success Reset	Success (Continuation Created) Reset	REDMOND\offsage on EJM0002 (U) de9723c4-ff80-4454-8b15-258d9953f616	Edit Copy Job Delete Reset Status
90	excel-xls-biff2 (cont. #3)	7/1/2011 8:35:17 PM		7/1/2011 8:46:00 PM	<input checked="" type="checkbox"/>	d:\sage\jobs\excel-xls-biff2_3		Success Reset	Success (Continuation Created) Reset	REDMOND\offsage on EJM0002 (U) e13b035b-d3d4-4aa4-9779-3a6a201bf965	Edit Copy Job Delete Reset Status
54	excel-xls-biff8	5/25/2011 10:08:40 AM	7/1/2011 7:25:42 PM	7/1/2011 11:57:31 PM	<input checked="" type="checkbox"/>	d:\sage\jobs\excel-xls-biff8	seeds	Success Reset	Success (Continuation Created) Reset	REDMOND\dozer on TWC-SAGEBB-0113 (U) 15372fb3-7f38-4f12-8e9a-4d5bc3a8b7a8	Edit Copy Job Delete Reset Status
52	excel-xls-biff4	5/25/2011 10:08:40 AM	7/1/2011 7:25:34 PM	7/1/2011 11:57:58 PM	<input checked="" type="checkbox"/>	d:\sage\jobs\excel-xls-biff4	seeds	Success Reset	Success (Continuation Created) Reset	REDMOND\dozer on EJM-0201 (U) 127bf840-243d-4e18-8620-83252d7e0745	Edit Copy Job Delete Reset Status
53	excel-xls-biff5	5/25/2011 10:08:40 AM	7/1/2011 7:25:39 PM	7/1/2011 11:59:35 PM	<input checked="" type="checkbox"/>	d:\sage\jobs\excel-xls-biff5	seeds	Success Reset	Success (Continuation Created) Reset	REDMOND\dozer on TWC-SAGEBB-0109 (U) 57308164-0f38-400c-a627-b23c9bd4a1f5	Edit Copy Job Delete Reset Status
56	excel-xls-sage-minset	5/25/2011 10:08:40 AM	7/1/2011 7:25:48 PM	7/2/2011 12:05:32 AM	<input checked="" type="checkbox"/>	d:\sage\jobs\excel-xls-sage-minset	seeds	Success Reset	Success (Continuation Created) Reset	REDMOND\dozer on TWC-SAGEBB-0101 (U) 51f8c275-3914-4296-8e18-ff6de18716f2	Edit Copy Job Delete Reset Status
61	project-mpp2003	5/25/2011 10:08:40 AM	7/1/2011 7:26:05 PM	7/2/2011 12:06:42 AM	<input checked="" type="checkbox"/>	d:\sage\jobs\project-mpp2003	seeds	Success Reset	Success (Continuation Created) Reset	REDMOND\dozer on TWC-SAGEBB-0107 (U) 5683c1e7-7bca-459a-b215-cdf8b10e020d	Edit Copy Job Delete Reset Status
59	project-mpp12	5/25/2011 10:08:40 AM	7/1/2011 7:25:59 PM	7/2/2011 12:07:01 AM	<input checked="" type="checkbox"/>	d:\sage\jobs\project-mpp12	seeds	Success Reset	Success (Continuation Created) Reset	REDMOND\dozer on TWC-SAGEBB-0110 (U) 6d579f78-527d-4f32-82f1-4d4231eeb2a4	Edit Copy Job Delete Reset Status
57	excel-xls-smartart	5/25/2011 10:08:40 AM	7/1/2011 7:25:52 PM	7/2/2011 12:08:24 AM	<input checked="" type="checkbox"/>	d:\sage\jobs\excel-xls-smartart	seeds	Success Reset	Success (Continuation Created) Reset	REDMOND\dozer on TWC-SAGEBB-0112 (U) d4dc4354-e280-4c43-806b-928f6666c951	Edit Copy Job Delete Reset Status
58	excel-xls-uex-cmdbars	5/25/2011 10:08:40 AM	7/1/2011 7:25:55 PM	7/2/2011 12:09:06 AM	<input checked="" type="checkbox"/>	d:\sage\jobs\excel-xls-uex-cmdbars	seeds	Success Reset	Success (Continuation Created) Reset	REDMOND\dozer on TWC-SAGEBB-0106 (U) aa20d348-b4e3-46e7-81c0-b3274fffe03e	Edit Copy Job Delete Reset Status

[1](#) [2](#) [3](#) [4](#) [5](#)

[Refresh](#) [New job](#)

Job details

[Edit](#) [Delete](#) [New](#)

JobID	54				
Title	excel-xls-biff8				
Creation	5/25/2011 10:08:40 AM				
Last Update	7/1/2011 7:25:42 PM				
Enabled	<input checked="" type="checkbox"/>				
Install Directory	d:\sage\jobs\excel-xls-biff8				
Seed File	seeds				
Config File	parallel.ini				
Extra Arguments	/logfile:sage.out				
Sage Path					
Install Status	Success Reset				
Run Status	Success (Continuation Created) Reset				
Assigned To	REDMOND\dozer on TWC-SAGEBB-0113 Unassign				
SaganRunID	15372fb3-7f38-4f12-8e9a-4d5bc3a8b7a8				
Backup Directory	\\officet4\sagestorage\$\excel-xls-biff8				
Files to Copy	<table><tr><th>Source</th><th>Destination Directory</th></tr><tr><td></td><td></td></tr></table>	Source	Destination Directory		
Source	Destination Directory				

Current status

Last Heartbeat	7/1/2011 11:57:31 PM
Machine Time	7/1/2011 11:57:57 PM
Deadline	7/1/2011 11:56:51 PM
Last Assignment	
Last StartTime	7/1/2011 8:56:42 PM
Last EndTime	7/1/2011 11:57:57 PM
MaxRunTime	45min
Estimated time sum	0
Estimated needed time	0
Heartbeat frequency	8s
Will create continuation	True

Task	QueueSize	AvgDuration	Running	Processed	Priorities
TestfileTask	0	4s 479ms	0	0	
CoverageTask	0	2min 8s 325ms	0	0	
TracerTask	0	0	0	0	
TruscanTask	0	0	0	0	
CleanupTask	0	15ms	0	0	

[Refresh](#)

Actions

[Reset Status](#) [Stop Now](#)

MaxRunTime [Set](#)

HeartbeatFreq [Set](#)

Loop control

AssignJobs: [On](#) / [Off](#)

ReadQueue: [On](#) / [Off](#)

ForceStayInLoop: [On](#) / [Off](#) / [Auto](#)

Stats: [On](#) / [Off](#)

CreateContinuation: [On](#) / [Off](#) / [Auto](#)

Move queue

ALL TASKS

Max number:

Max percentage:

Max estimated time:

Max size:

☐ if MaxRunTime will be exceeded

Destination: \\officet4\sagestorage\$\

[Move queue](#) [Copy queue](#) [Delete queue](#)

Passage log messages

Clean log messages [All](#) [Before last start](#)

Debug messages 526

Error messages 0

7/1/2011 11:57:57 PM	Continuation job added successfully: #92
7/1/2011 11:57:40 PM	MoveQueue: 0 directory moved, Success
7/1/2011 11:57:40 PM	MoveQueue: 0 directory moved, Success
7/1/2011 11:57:40 PM	MoveQueue: 1 directory moved, Success
7/1/2011 11:55:25 PM	MoveQueue: 1 directory moved, Success
7/1/2011 11:54:55 PM	MoveQueue: 1 directory moved, Success
7/1/2011 11:54:25 PM	MoveQueue: 0 directory moved, Success
7/1/2011 11:53:56 PM	MoveQueue: 0 directory moved, Success
7/1/2011 11:53:25 PM	MoveQueue: 0 directory moved, Success

Local intranet | Protected Mode: Off

DFF Integration

Distributed Fuzzing Framework - Run Statistics: Current Run Statistics - Windows Internet Explorer

http://oa-dffdb-01/runs/statistics/current.aspx

Home System Statistics Run Statistics Run Results Run Management Client Management Settings

Current Runs Uninvestigated Runs View All Runs

Distributed Fuzzing Framework Run Statistics: Current Runs

Current Runs

Run that are that are not complete or expired but are queued (or active), private, or disabled.

Filter By: Run Status: Team: Application:

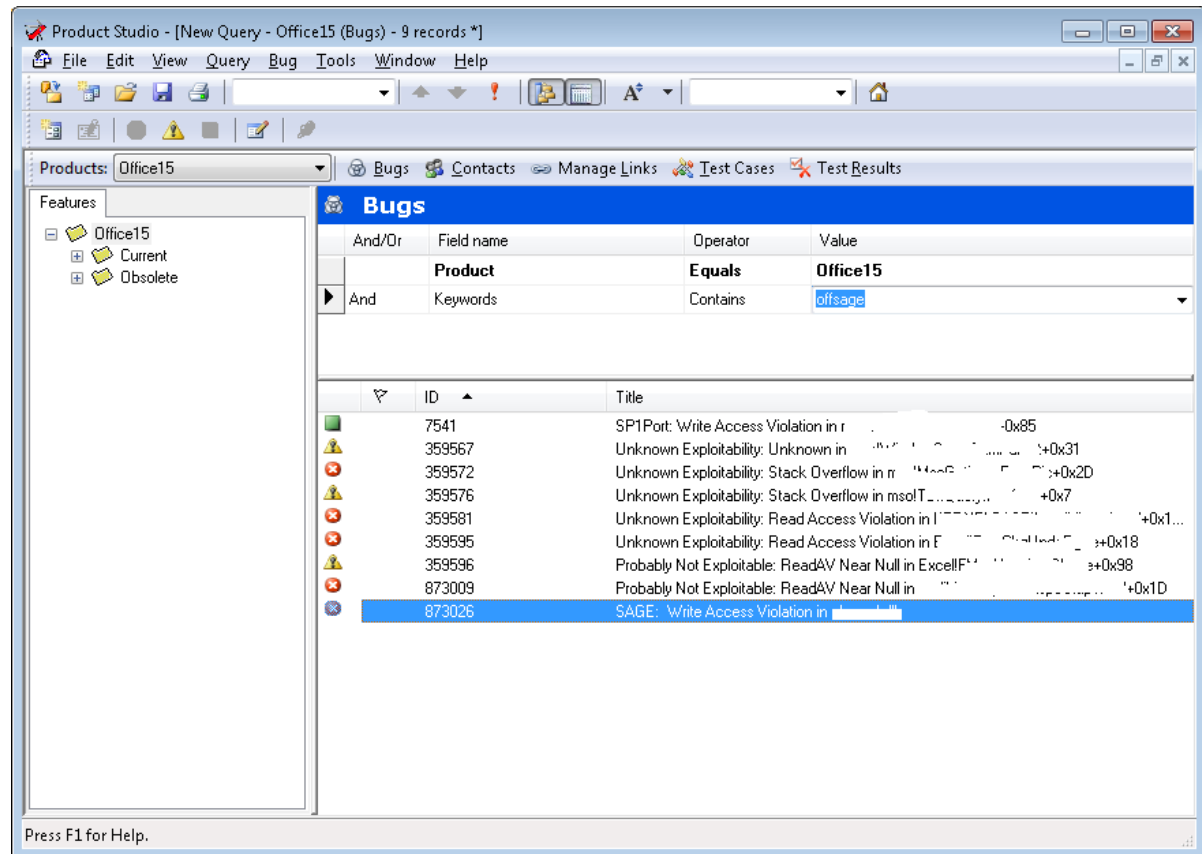
Show: ☒ Only Where I am Owner

ID	Team	Application	Name	% Complete	Size	Processed	Failed	Without Bugs	Machines	Q	P	D	Edit	Results
34154	Visio	Visio 15	Visio VSTM VSTM 15.0.2801.1000 Generated	0%	50000	0	0	0	0/50	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Edit	Results
34155	Visio	Visio 15	Visio VSTX VSTX 15.0.2801.1000 Generated	0%	50000	0	0	0	0/50	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Edit	Results
35461	Visio	Visio 15	Visio VSTM VSTM 15.0.2913.1000 Generated	0%	50000	0	0	0	0/50	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Edit	Results
36510	OSF	Excel 15	SequentialXmlFuzzer XSLX	0%	2913	0	0	0	0/X	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Edit	Results
36511	OSF	Word 15	SequentialXmlFuzzer DOCX	0%	1653	0	0	0	0/X	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Edit	Results
36515	TWC	Excel 15	SAGE Fuzzer: Excel-XLS-x86 [7/6/2011 12:16 PM]	0%	3548	0	0	0	0/1	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Edit	Results
36516	TWC	Excel 15	SAGE Fuzzer: Excel-XLS-x64 [7/6/2011 12:17 PM]	0%	3548	0	0	0	1/1	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Edit	Results
36517	TWC	Word 15	SAGE Fuzzer: Word-DOT-x86 [7/6/2011 12:17 PM]	0%	252	0	0	0	0/1	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Edit	Results
36518	TWC	Word 15	SAGE Fuzzer: Word-DOT-x64 [7/6/2011 12:17 PM]	0%	252	0	0	0	1/1	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Edit	Results
36519	TWC	Word 15	SAGE Fuzzer: Word-DOC-x86 [7/6/2011 12:18 PM]	0%	1726	0	0	0	0/1	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Edit	Results
36520	TWC	Word 15	SAGE Fuzzer: Word-DOC-x64 [7/6/2011 12:18 PM]	0%	1726	0	0	0	0/1	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Edit	Results
36521	TWC	Project 15	SAGE Fuzzer: Project-MPP-x86 [7/6/2011 12:19 PM]	0%	1702	0	0	0	0/1	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Edit	Results
36522	TWC	Project 15	SAGE Fuzzer: Project-MPP-x64 [7/6/2011 12:20 PM]	0%	1702	0	0	0	0/1	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Edit	Results
36238	Visio	Visio 15	Visio VSDM VSDM 15.0.3013.1000 Generated	0%	50000	0	0	0	0/50	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Edit	Results
36239	Word	Word 15	SequentialHtmlFuzzer HTM 15.0.3013.1000 Generated	0%	50000	0	0	0	0/25	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Edit	Results
36248	Visio	Visio 15	Visio VSDX VSDX 15.0.3013.1000 Generated	0%	50000	0	0	0	0/50	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Edit	Results
36249	Visio	Visio 15	Visio VSSX VSSX 15.0.3013.1000 Generated	0%	50000	0	0	0	0/25	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Edit	Results
36250	Visio	Visio 15	Visio VSSM VSSM 15.0.3013.1000 Generated	0%	50000	0	0	0	0/25	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Edit	Results
36271	Visio	Visio 15	Renren VSD VisioViewer Run VSD 15.0.3013.1000 Gener	0%	50000	0	0	0	0/50	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Edit	Results

Local intranet | Protected Mode: Off 100%

Results

- No failed run due to low disk space on M3
 - 9 found bugs on Office
- + more on the pipeline
(200,000 files sent to DFF)



Future work:

Towards SAGE Fuzzing anywhere

- Formulate finding bugs problem as an optimization problem
- SAGE will auto-adapt to changes in its environments: new machines, new jobs, configuration changes at runtime, ...
- Benefits Windows, Office and all other parser-based Microsoft software

Summary

- Solved low disk space issues
- Made the state persistent
- Made the migration of jobs possible
- Implemented one solution for the three scenarios (dedicated machines, Big Button Lab, DFF)
- Easy-to-use Job Center
- Found bugs!



Thanks to the entire SAGE team and users!

- **MSR**: Ella Bounimova, Patrice Godefroid, David Molnar
(+ our managers for their support! 😊)
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- **Windows**: Nick Bartmon, Eric Douglas, Dustin Duran, Elmar Langholz, Isaac Sheldon, Dave Weston, ...
 - Win8 TruScan support: Evan Tice, David Grant,...
- **Office**: Tom Gallagher, Eric Jarvi, Octavian Timofte, ...
- **MSEC**: Dan Margolis, Matt Miller, Lars Opstad, Jason Shirk, ...
- **SAGE users all across Microsoft!**
- Download SAGE: <http://sharepoint/sites/SAGE>