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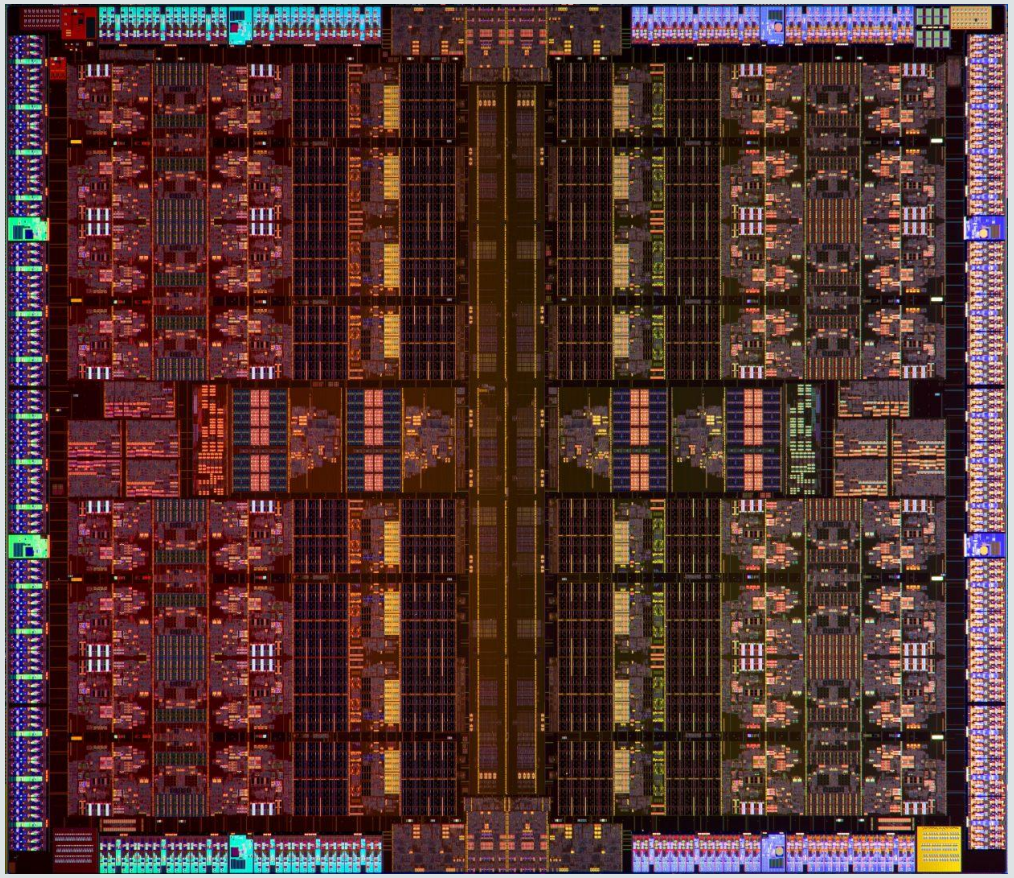
Mit Silicon Secured Memory Heartbleed und Co. vorbeugen

Franz Haberhauer
Chief Technologist
Systems Sales Consulting Northern Europe



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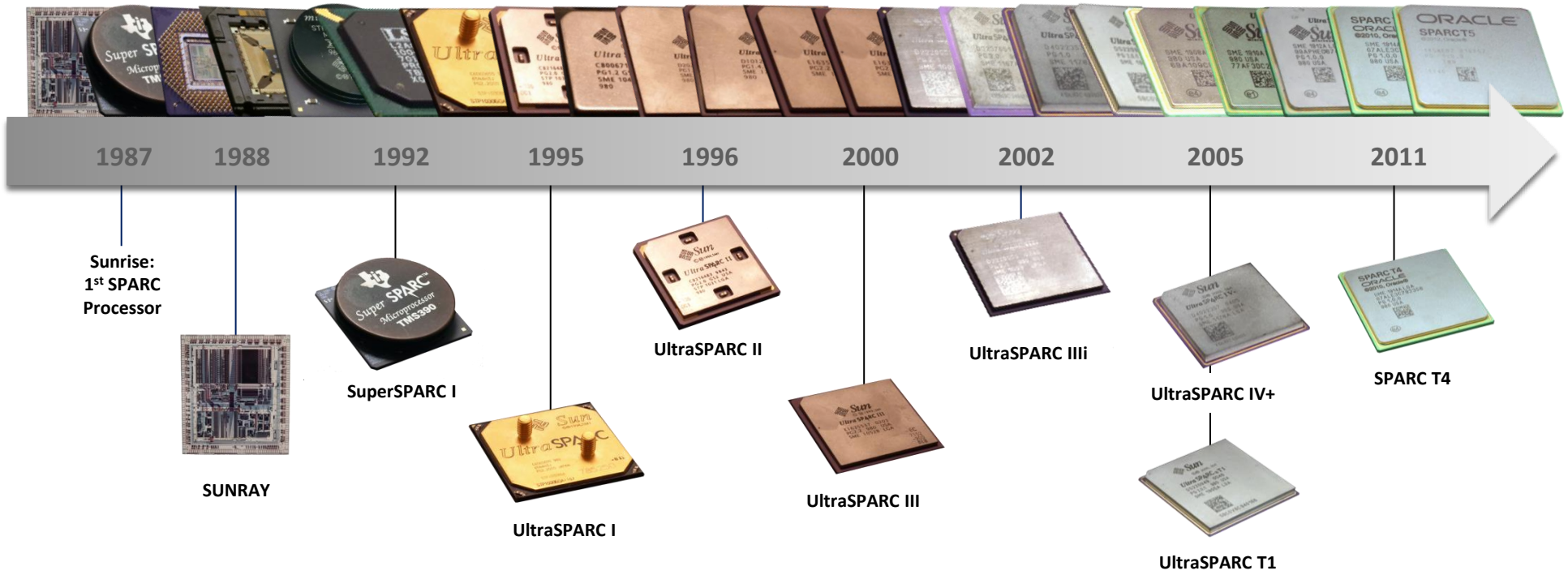
Chip Advances in the Last Decade

- Focus on better/faster general purpose chip
- More CPU cores per chip
- Memory & PCI interfaces, GPU moved on-chip
- Improved pipelines, branch prediction, cache coherency, reliability, clock rates, power management etc.
- **New Functionality**: vector processing/SIMD, virtualization, **encryption**
  - Encryption on-chip is 10X faster and frees CPU cores to do other work
  - Database optimizations on chip are analogous

2012 – 25 Years of SPARC Processors



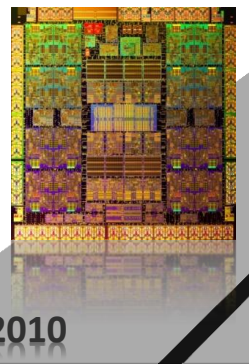
Anniversary Video: http://www.youtube.com/watch?v=IKB9zV8TXuQ
Infographic: http://www.oracle-downloads.com/sparc25info/

SPARC @ Oracle

7 Processors in 6 Years

Including Software in Silicon

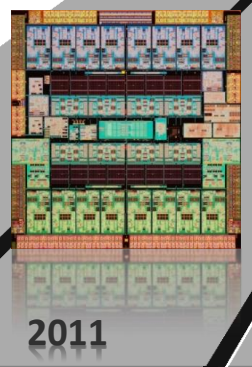
- Silicon Secured Memory
- DB Query Acceleration
- Inline Decompression
- More….



2010

SPARC T3

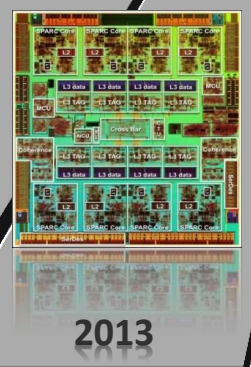
16 x 2nd Gen cores
4MB L3 Cache
1.65 GHz



2011

SPARC T4

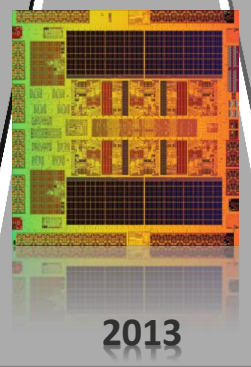
8 x 3rd Gen Cores
4MB L3 Cache
3.0 GHz



2013

SPARC T5

16 x 3rd Gen Cores
8MB L3 Cache
3.6 GHz



2013

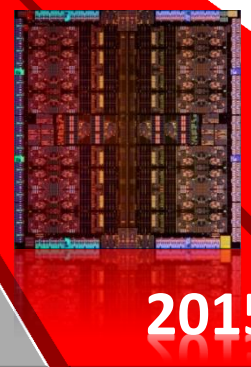
SPARC M5

6 x 3rd Gen Cores
48MB L3 Cache
3.6 GHz

2013

SPARC M6

12 x 3rd Gen Cores
48MB L3 Cache
3.6 GHz

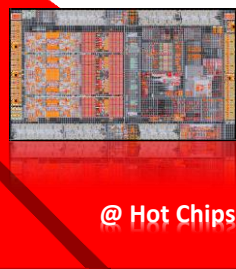


2015

SPARC M7

32 x 4th Gen Cores
64MB L3 Cache
4.1 GHz

Current
T7-/M7-Servers



@ Hot Chips 2015

'SONOMA'

8 x 4th Gen Cores
IB

Scale-Out
Servers TBA.

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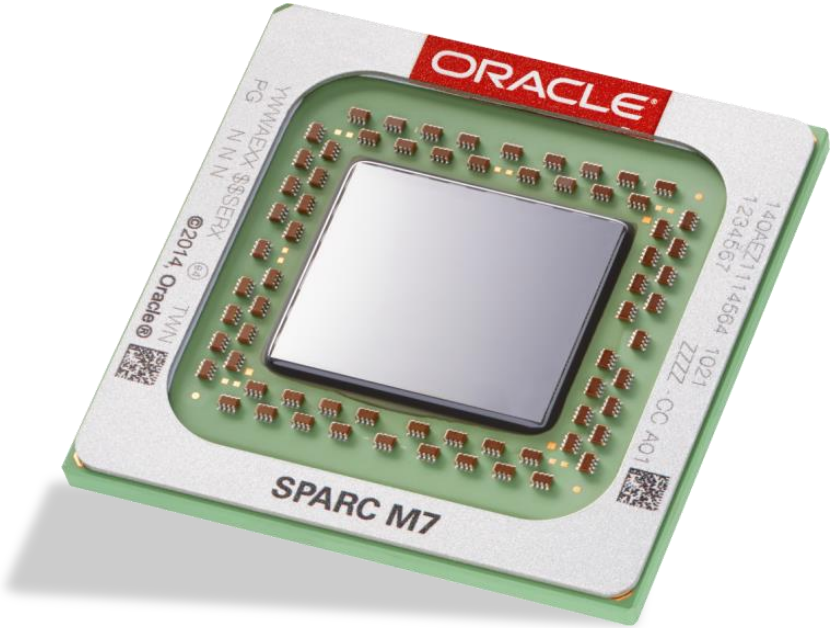
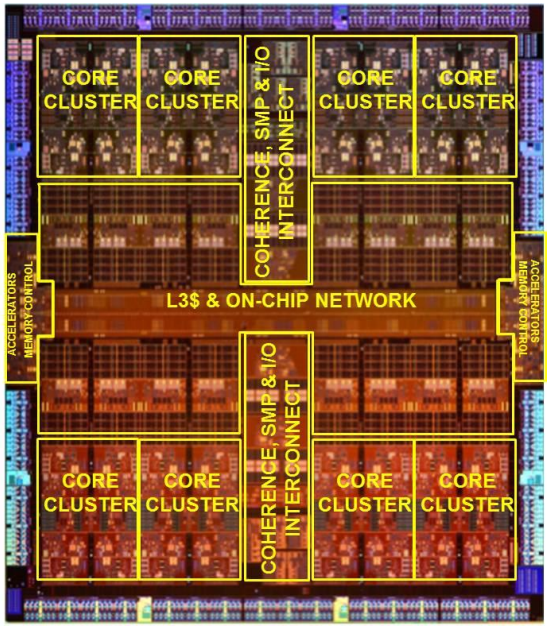
It Does not Take Much Die to Make a Difference
SPARC M7





2x-3x More Throughput Performance (16 -> 32 Cores) **with** **30 to 40% More Single Thread Performance** **and** **Over 2x More Encryption Bandwidth** **Plus**

Software in Silicon:
Security in Silicon
SQL in Silicon
Capacity in Silicon

< 1% of Die

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SPARC T7 and M7 Systems





	T7-1	T7-2	T7-4	M7-8	M7-16
Processors	1	2	2 or 4	Up to 8 [1]	Up to 16 [2]
Max Cores	32	64	128	256	512
Max Threads	256	512	1,024	2,048	4,096
Max Memory [3]	.5 TB	1 TB	2 TB	4 TB	8 TB
Form Factor	2U	3U	5U	Rack / 10U	Rack
Domaining	LDOMs	LDOMs	LDOMs	LDOMs, PDOMs [1]	LDOMs, PDOMs [2]

(1) Factory configured with one (up to 8 processors) or two (up to 4 processors each) static physical domains
(2) 1, 2, 3 or 4 reconfigurable physical domains
(3) Maximum memory capacity is based on 32 GB DIMMs

http://oracle.com/m7infowall -> White Paper M7 Systems Architecture
https://blogs.oracle.com/bestperf

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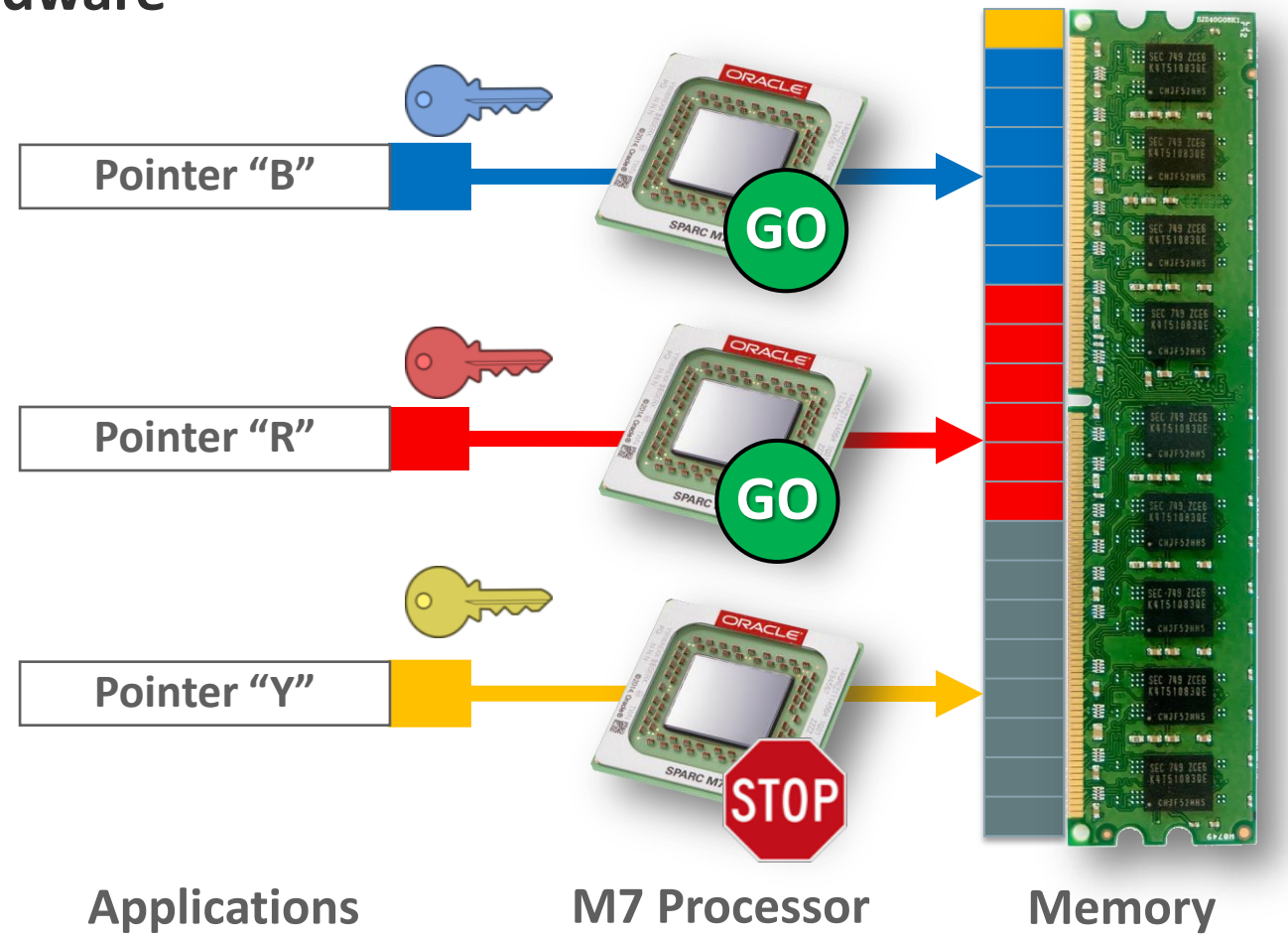
Silicon Secured Memory

Application Data Integrity (ADI)

Oracle M7 Silicon Secured Memory

Always-On Memory Protection in Hardware

- **Protects data in memory**
- Hidden “color” bits added to *pointers* (key) and content (lock)
- Pointer color (key) must match content color or program is aborted
  - Set on *memory allocation*, changed on *memory free’*
  - Protects against *access off end of structure*, *stale pointer* access and malicious attacks



Oracle M7 Silicon Secured Memory

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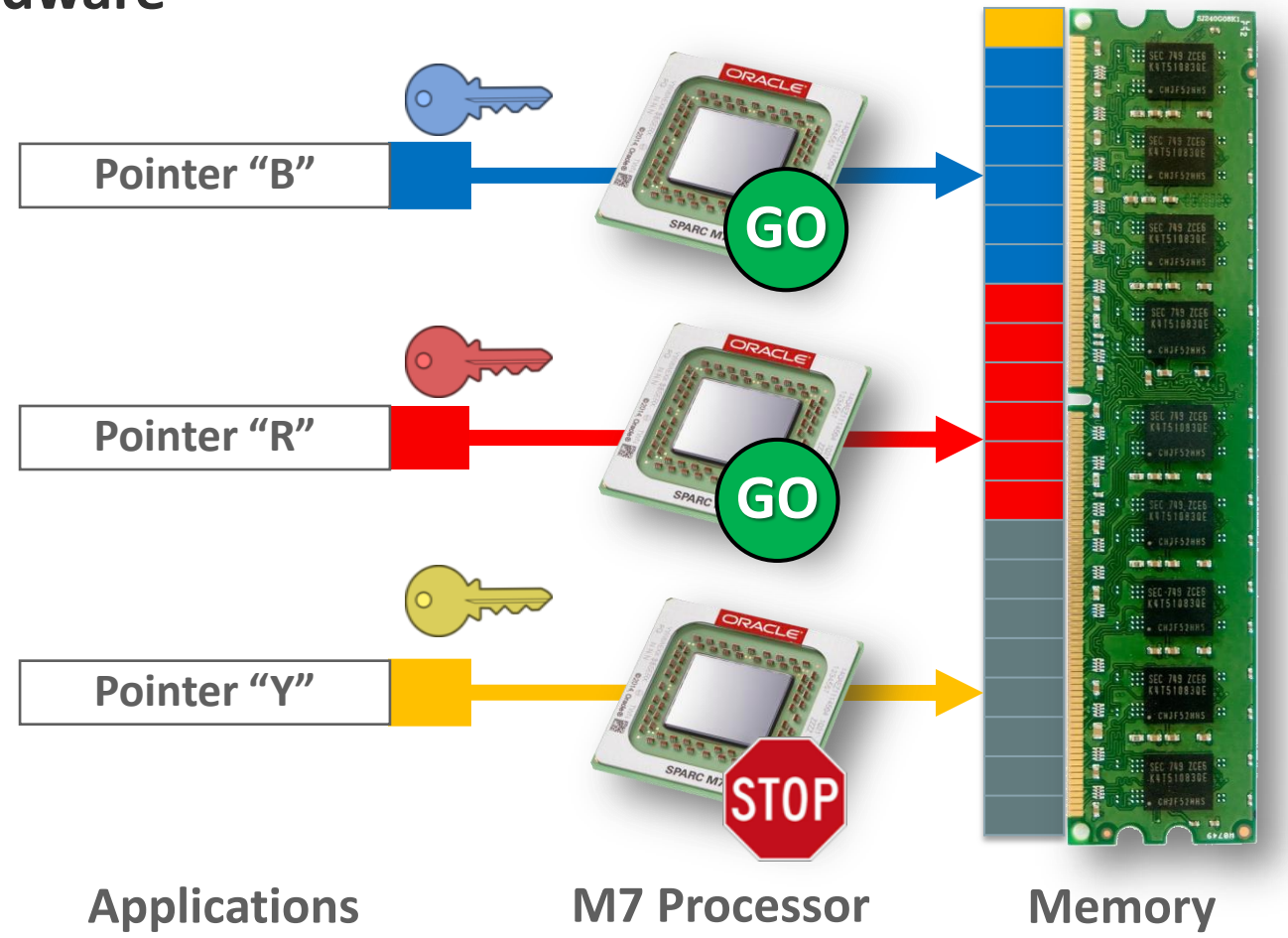
  - Set on *memory allocation*, changed on *memory free’*
  - Protects against *access off end of structure*, *stale pointer* access and malicious attacks
- **Extremely efficient for software development**

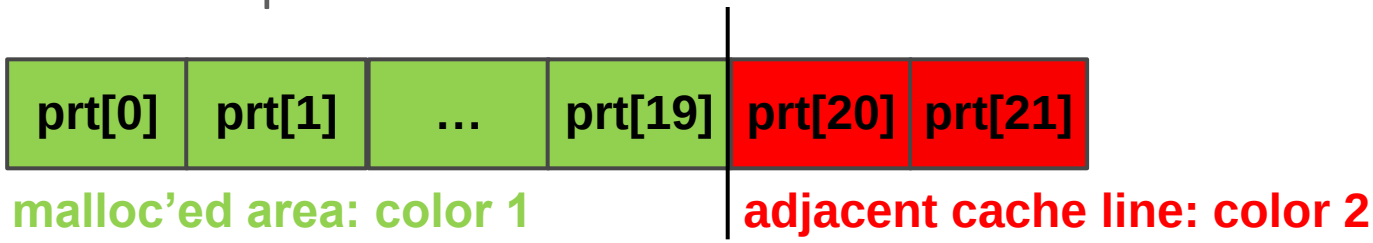


Linear Buffer Overflows

- ADI is really great at detecting **linear overflows**
- The attacker controls the size of the buffer being written, but not the starting address

```
char *ptr;
ptr = malloc(20);
strcpy(ptr, argv[1]); /* argv could be bigger than 20 chars */
```

  - The overflowed memory is **adjacent** to the buffer. Other live buffers, free buffers and potentially metadata may become corrupted
  - As long as the buffer adjacent to the one allocated for *ptr* has a different ADI color, any attempt to overflow will trap



A Couple of Famous Examples: Heartbleed & Venom

Silicon Secured Memory Protection From Read and Write Attacks

Buffer Over-Read Attack

Buffer Over-Write Attack

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Heartbleed - Impacted Websites Using OpenSSL

Heartbeat request sent to victim

Type	Payload_size	Payload
HB_REQUEST	65535	Hello

Payload_size does not match Payload

Victim responds with requested payload size (64K bytes)

Type	Payload_size	Payload
HB_RESPONSE	65535	Hello ……

Unauthorized data returned to requestor

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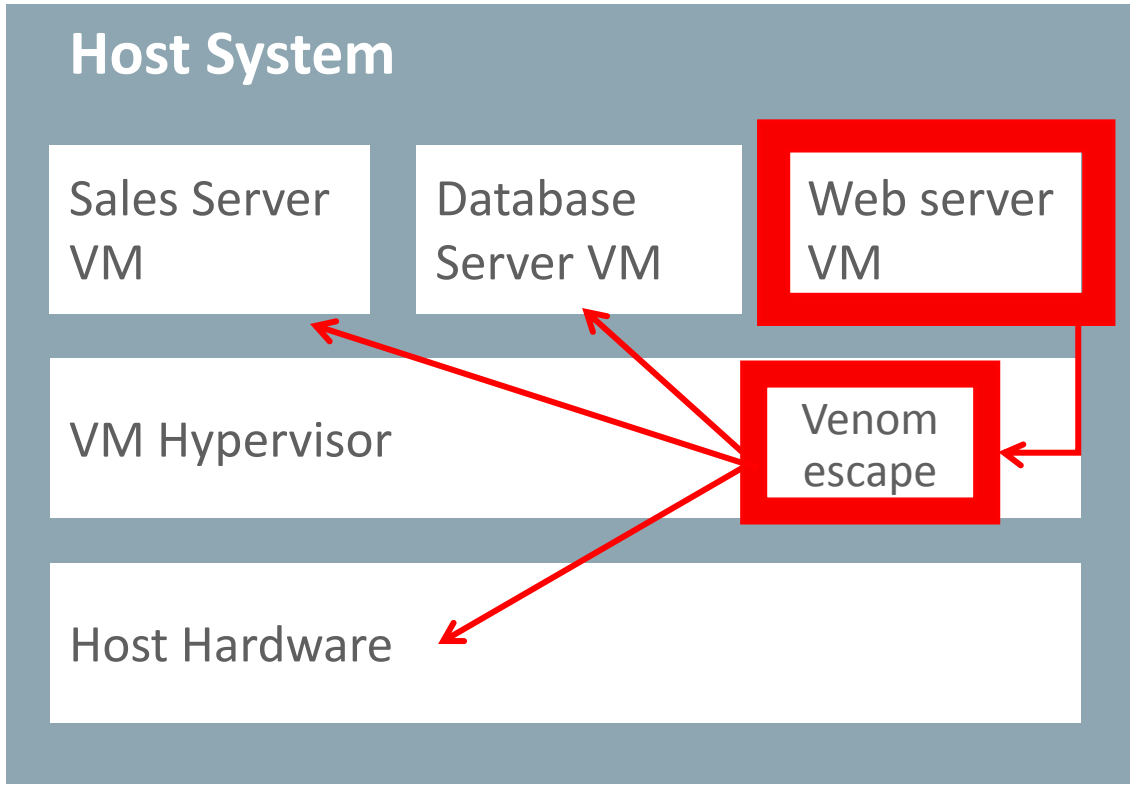
Venom Vulnerability - Impacted Servers Using QEMU



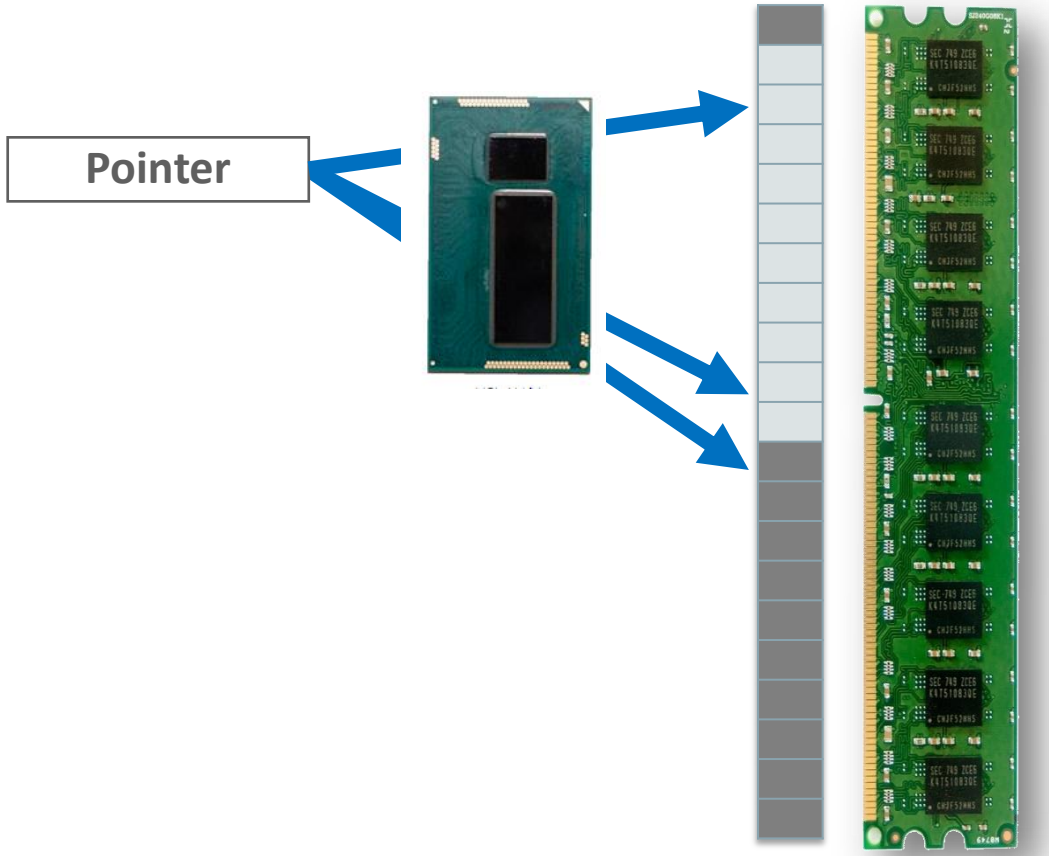
Hacker exploits VENOM to escape VM

VENOM executes instructions in hypervisor and gains control of host hardware

- Memory access vulnerability discovered in the open source Quick Emulator hypervisor platform (QEMU)
- Allows malicious code inside a VM guest to execute code in the host machine's hypervisor security context. The code then escape the guest VM to gain control over the entire host
- Caused by a buffer over-write condition that allows data to be stored beyond allocated buffer limits

Silicon Secured Memory: Buffer Overflows

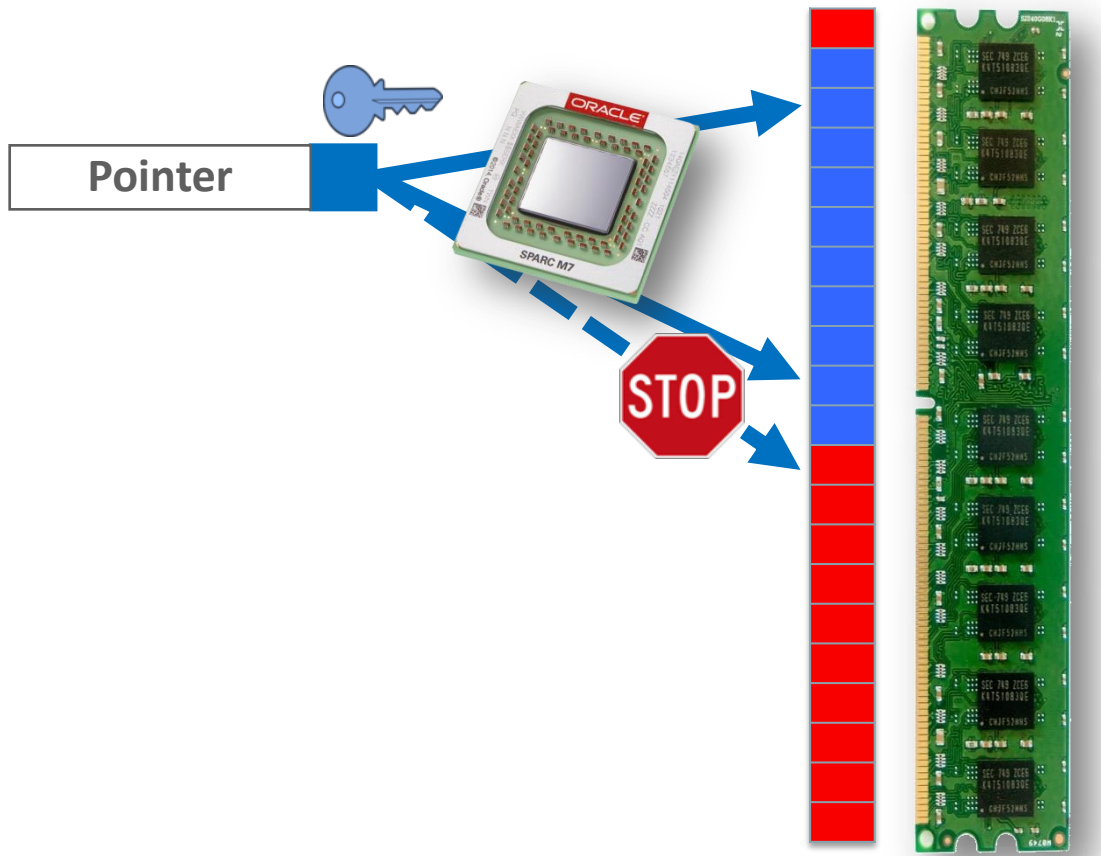
Any Processor



Applications

Memory

SPARC M7Processor



Applications

Memory

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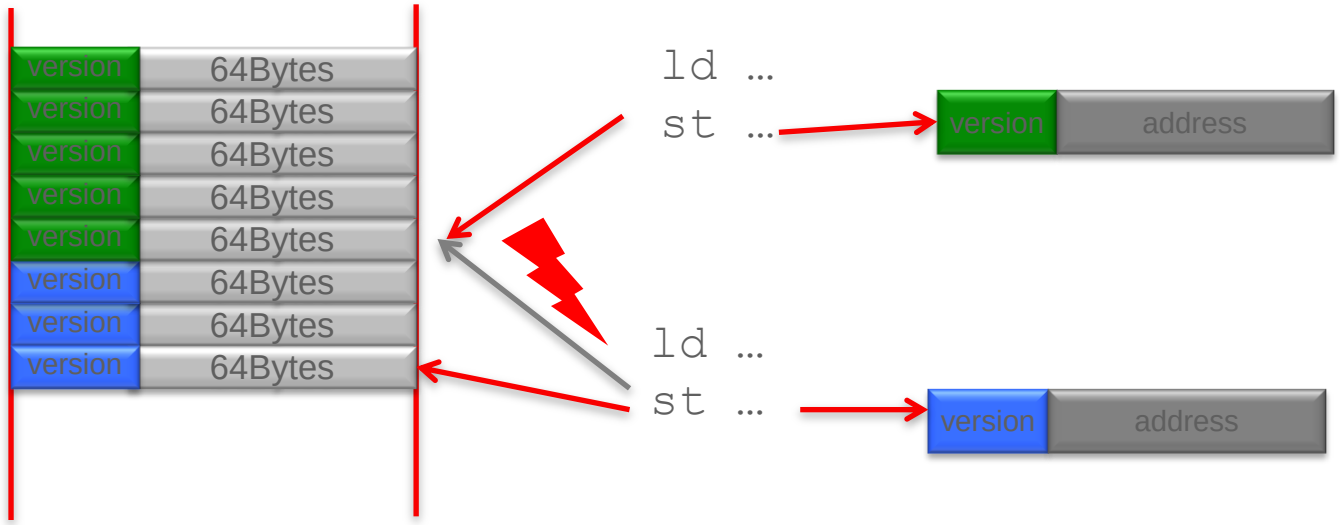
SSM Implementation: Application Data Integrity



(dbx) run
signal SEGV (ADI version 13 mismatch for VA 0x4a900) in main at 0x10988
(dbx) where
…stack trace…

- H/W compares pointer "key" with memory "lock"
  - are 4bit numbers
  - called "versions"
- Traps if they don't match
  - Sends SEGV or utrap to process
- H/W masks "key" before it hits the MMU

ADI version numbers and coloring

- *version* numbers use 4 bits
  - Valid range : 1 – 13
    - 0, 14 and 15 are reserved for system usage
    - By default all the memory is tagged with 0
    - 0 is not a valid *version* value for ADI checking
- Adjacent area paradigm
  - Adjacent areas are tagged with different version numbers
  - 4 bits are sufficient to tag uniquely adjacent buffers (for alloc and free)
  - Example

```
int *ptr = malloc(128);
free(ptr);
```

will set *version* as follow:

ptr[offset] (int)	version # (malloc)	version # (free)	notes
0 - 31	1	8	malloc'ed area
32 - 47	8	8	uphill adjacent cache line (the downhill adjacent cache line is not tagged)

Silicon Secured Memory

Support for Both Development and Deployment

DEVELOPMENT: Studio provides detailed diagnostics for developers to find and fix memory corruptions

DEPLOYMENT: Solaris enables applications to take appropriate recovery actions in real-time *

Solaris Studio 12.4/12.5 Beta *discover* tool

libdiscoveradi

libadimalloc

Solaris Kernel
(Provides syscalls for user-level applications)

SPARC M7 hardware
(Enables software stack for Silicon Secured Memory checking)

* App must be coded to use ADI APIs

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Example Use of `libadimalloc.so`

Demo Code

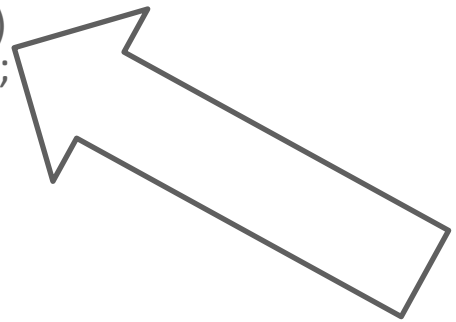
```
#include <stdio.h>
#include <stdlib.h>

int
main(void){
  char* public = (char*)malloc(sizeof(char)*100);
  char* secret = (char*)malloc(sizeof(char)*100);

  printf("public text -> ");  scanf("%s", public);
  printf("secret text -> ");  scanf("%s", secret);

  for(int ii = 0; ii < 150; ii++)
    printf("%c\n", public[ii]);

  printf("\n");
  return 0;
}
```



- Obvious Buffer Overflow (read beyond end)
- “public” buffer is 100bytes wide
- Code reads 150bytes
  - 50bytes are read from adjacent buffer

Output of Demo

On any system

```
franzh@SPARC-M7,ADI>./malloc
public text -> hello
secret text -> secret
h
e
l
l
o
---snip---

s
e
c
r
e
t
---snip---
franzh@SPARC-M7,ADI>
```

On a SPARC M7 using `libadimalloc.so`

```
franzh@SPARC-M7,ADI>
  LD_PRELOAD=libadimalloc.so ./malloc
public text -> hello
secret text -> secret
h
e
l
l
o
---snip---

Segmentation Fault (core dumped)
franzh@SPARC-M7,ADI>
```

Silicon Secured Memory

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Solaris Studio 12.4/12.5 Beta *discover* tool

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Oracle Solaris Studio

Solaris & Linux, SPARC & x86, Remote Development

Multi-language Development

C, C++, Fortran Compilers

Debugger

Performance Library

Java

Application Analytics

Code Analyzer

Performance Analyzer

Thread Analyzer

Extensible IDE

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Oracle Solaris Studio

Using discover and ADI to Find Memory Access Errors

- libdiscoverADI.so
  - enables discover to detect and understand runtime-related memory errors identified by ADI
    - `% LD_PRELOAD_64=<compiler>/lib/compilers/sparcv9/libdiscoverADI.so a.out`
    - `% discover -i adi a.out`
      `% a.out`
  - prints a comprehensive error analysis report for memory errors (text or html)

```
$ a.out
ERROR 1 (UAW): writing to unallocated memory at address 0x50088 (4 bytes) at: main() + 0x2a0 <ui.c:20>
17: t = malloc(32);
18: printf("hello\n");
19: for (int i=0; i<100;i++)
20:=> t[32] = 234; // UAW
21: printf("%d\n", t[2]); //UMR
22: foo();
23: bar();
_start() + 0x108 ERROR 2 (UMR): accessing uninitialized data from address 0x50010 (4 bytes) at: main() + 0x16c <ui.c:21>$
...
```

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Oracle Solaris Studio 12.5 Beta: Discover and Uncover User's Guide - **Memory Error Discovery Tool (discover)**
https://docs.oracle.com/cd/E60778_01/html/E60755/gmzsf.html

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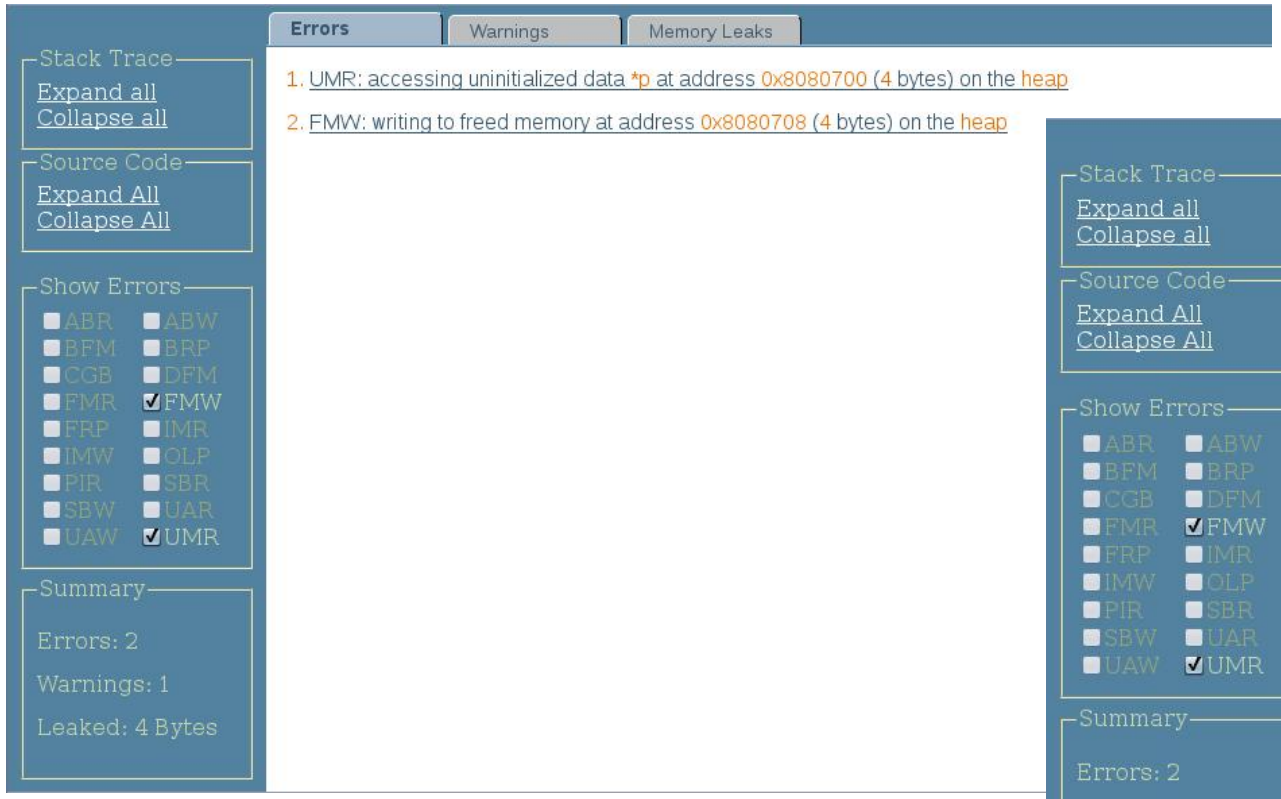
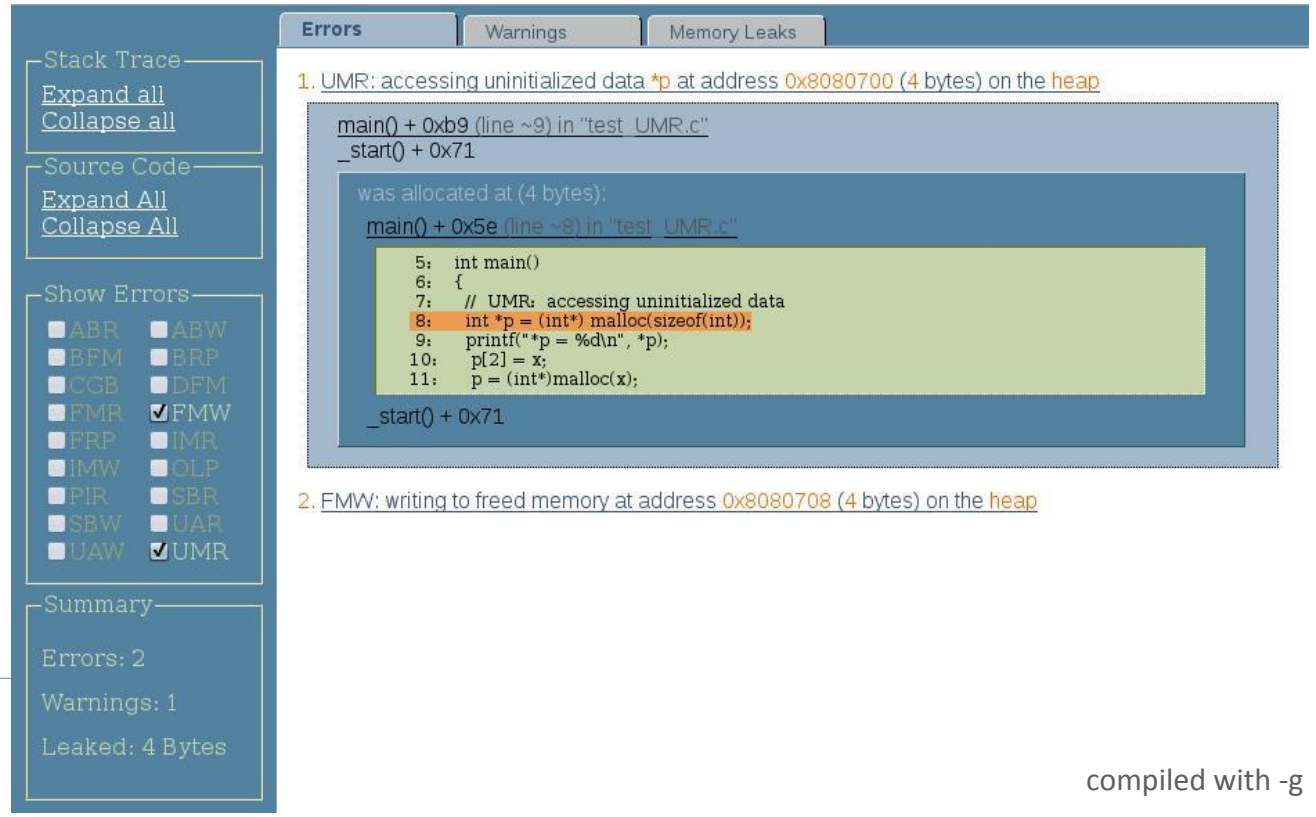
Interactively Analyzing discover HTML-Report





compiled with -g

Oracle Solaris Studio 12.5 Beta: Discover and Uncover User's Guide – **Analyzing discover Reports**
https://docs.oracle.com/cd/E60778_01/html/E60755/gjzce.html

Oracle Solaris Studio

Code Analyzer: GUI to Navigate Tool Results

Oracle Solaris Studio Code Analyzer

File View Tools Window Help

Issues Sources

Issues: Core All

Analysis
Dynamic (1)
Severity
ERROR (1)
Bug type: ABR
ABR (Beyond Arra
ABW (Beyond Arr
OLP (Overlapping
UMR (Uninitialized
Binaries
libnsl.so.1
openssl (1)
Files
t1_lib.c (1)

Open Analysis | Results | Details Window | t1_lib.c

Showing 1 Issues Show: Snippets Reviewed Ignored New Fixed

ABR Beyond Array Bounds Read: at address 8ccc9eb (65535 bytes) on the heap

/export/sheldon/openssl/openssl-1.0.1f/ssl/t1_lib.c:2586

```
2583:           /* Enter response type, length and copy payload */
2584:           *bp++ = TLS1_HB_RESPONSE;
2585:           s2n(payload, bp);
2586:           memcpy(bp, pl, payload);
2587:           bp += payload;
```

Stacktrace

Call Stack
- **tls1_process_heartbeat** at t1_lib.c:2586
- **ssl3_read_bytes** at s3_pkt.c:1092
- **ssl3_get_message** at s3_both.c:458
- **ssl3_check_client_hello** at s3_srvr.c:882
- **ssl3_accept** at s3_srvr.c:581
- **SSL_accept** at ssl_lib.c:940
- **ssl23_get_client_hello** at s23_srvr.c:634
- **ssl23_accept** at s23_srvr.c:210

Allocated At Stack (size 17,736)
- **default_malloc_ex** at mem.c:79
- **CRYPTO_malloc** at mem.c:308
- **freelist_extract** at s3_both.c:708
- **ssl3_setup_read_buffer** at s3_both.c:770
- **ssl3_setup_buffers** at s3_both.c:827
- **ssl23_get_client_hello** at s23_srvr.c:266
- **ssl23_accept** at s23_srvr.c:210
- **ssl23_read** at s23_lib.c:127

Error Type

Memory Freed

Memory Allocated

Oracle Solaris Studio 12.5 Beta: **Code Analyzer User's Guide**
https://docs.oracle.com/cd/E60778_01/html/E60757

Errors Caught by discover and ADI

- Buffer overflow errors

```
int *area1 = malloc(sizeof(int)*16);
for (int i = 0; i <= 16; i++)
      area1[i] = 0;      // Array Out of Bounds
```

- Freed memory access errors

```
free(area1);
area1[0] = 0; // Freed memory access error
```

- Stale pointer memory access errors

```
int *area1 = malloc(sizeof(int)*16);
free(area1);
char *area3 = malloc(sizeof(char)*64); // area3 gets the memory area just
freed by area1 area1[0] = 0; // Stale Pointer Access
```

- Double free memory access errors

```
free(area3);
free(area3); // double free
```

Silicon Secured Memory Developer Tool: *discover*

- *Discover* detects runtime memory access violations and memory leaks
- *Discover* provides detailed diagnostics to find and fix these errors
- Studio 12.5 *discover* uses M7 Silicon Secured Memory, making violation detection significantly faster than a software-only approach

- **[ABR | ABW] – Beyond Array Bounds Read/Write**
- **[FMR | FMW] – Freed Memory Read/Write**
- [IMR | IMW] – Invalid Memory Read/Write
- **[UAR | UAW] – UnAllocated memory Read/Write**
- [NAR | NAW]– Non-Annotated Read/Write
- [SBR | SBW]- beyond Stack Bounds Read/Write
- BFM – Bad Free Memory
- BRP – Bad Realloc address Parameter
- CGB – Corrupted Guard Block
- **DFM – Double Freeing Memory**
- PIR – Partially Initialized Read
- UMR – Uninitialized Memory Read
- OLP – Overlapping source and dest
- AZS – Allocating Zero Size
- SMR– Speculative Memory Read
- [UFR | UFW] – Unknown stack Frame Read/Write
- [USR | USW] – Unknown Status while Read/Write

Oracle Solaris Studio 12.5 Beta: Code Analyzer User's Guide – **Dynamic Memory Access Errors**
https://docs.oracle.com/cd/E60778_01/html/E60757/glmrb.htm
Code Analyzer previse may detect additional error types through static code analysis
https://docs.oracle.com/cd/E60778_01/html/E60757/glmsy.html

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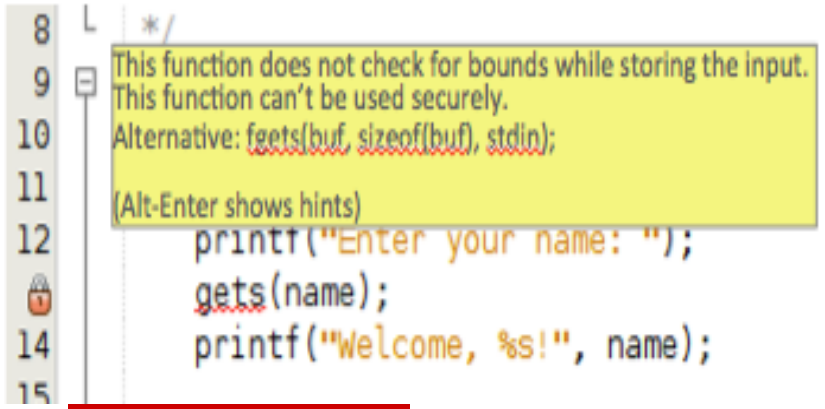
Studio 12.5: Security Features beyond SSM

1. Write Secure Code

- IDE identifies unsafe code
  - Uses Solaris C guidelines and some CERT C/C++ rules
- Explains issue and offers a more secure alternative



2. Build Secure Code

- Source code analysis done with every compile by default
  - previse
- Checks include:
  - Beyond array bounds access
  - Freed memory
  - Memory leaks

```
$ cc -O –c  test.c
”test.c", line 5: Warning: Likely out-of-bounds
read: a[i] in function main
```

3. Run Secure Code

- Compiler includes checks in every app to catch:
  - Stack overflow [*-xcheck=stkovf*]
  - Falling off the end of a routine [*-xcheck=noreturn*]

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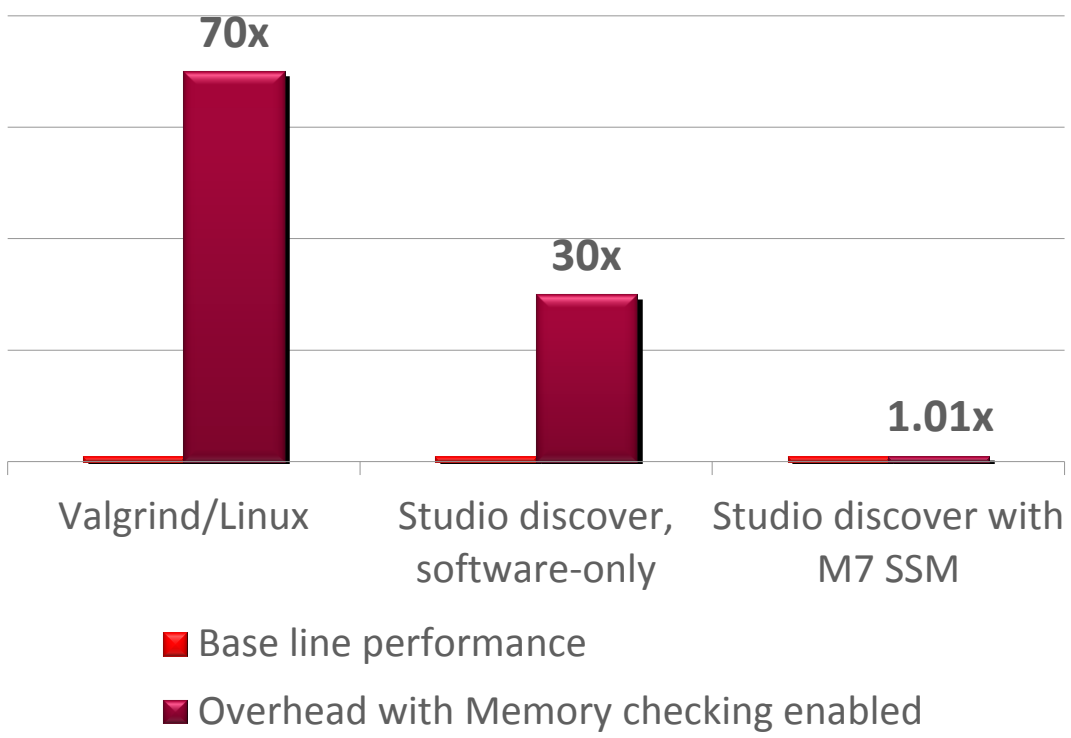
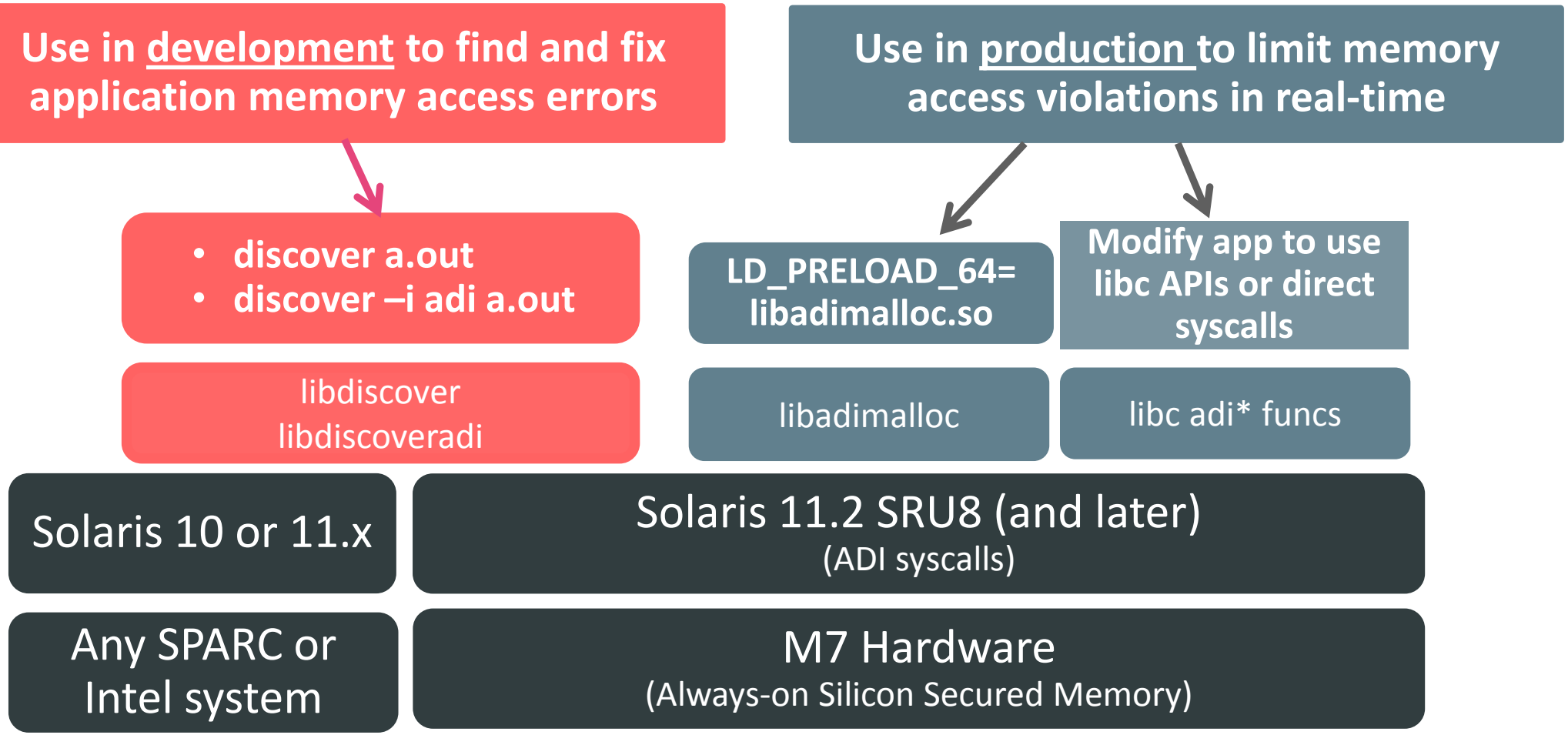
Developer's Guide to Oracle Solaris 11 Security - **Secure Coding Guidelines for Developers** http://docs.oracle.com/cd/E53394_01/html/E54753/scode-1.html
Appendix G: Security Considerations When Using C Functions http://docs.oracle.com/cd/E53394_01/html/E54753/gnclc.html

Developing Secure Software using Oracle Solaris Studio

- How Discover SSM works
  - Interposes on mem allocation routines
  - Assigns versions to pointers; ensures version doesn't match a neighbor's version
  - Catches the SEGV traps when illegal access occurs (i.e. version mismatch)
  - Collects error source line/stack trace and allocation/free source line/stack trace, then allows app to continue
  - Generates report of all recorded errors at end of run



Silicon Secured Memory for Both Development & Production



Low Level SSM – Solaris ADI API

Custom Memory Allocator

- An application needs to meet the following requirements for ADI code checking
  - The application binary must be built in 64-bit mode
  - The application needs to enable ADI on the target memory area
  - The allocated memory needs to be 64-byte aligned and its size must be multiple of 64
  - The allocated area should be set a version number
    with the pointer value being adjusted with the corresponding version number.
  - Complex pointer manipulation should be avoided, but simple pointer operations works

Custom Memory Allocator

Example

- Memory allocator needs to maintain version data
  - Writes version into memory during allocation
  - Returns pointer with version embedded
  - Allocator writes different version to cache line when freed
- 2 ranges of version numbers: one for memory **allocation** and one memory **free**

1 : used for the area of block object including block buffer
2 – 7 : used for the allocated name locations inside the block buffer
8 – 13 : used for the freed name locations inside the block buffer
mapping : 2 - 8, 3 - 9, 4 - 10, 5 - 11, 6 - 12, 7 - 13

ADI'fying Custom Memory Allocators

64-bit mode	cc –m64

Memory ADI enabled	`large_block_ptr = (large_block*) memalign(8192, 64 * 1024);`
	`memcntl(large_block_ptr, 64 * 1024, MC_ENABLE_ADI,NULL,0,0)`
	- Both address and size must be PAGESIZE (8k) aligned

64-bit alignment	`object_ptr = (my_object*) my_malloc(sizeof(my_object));`
	needs to be changed to:
	`adjusted_size = (sizeof(my_object) + 63) & ~63; // adjust to multiple of 64`
	`object_ptr = (my_object*) my_malloc(64,adjusted_size); // 64-byte aligned`

Version numbers	`adjusted_object_ptr = (my_object*)` `  adi_set_version(object_ptr, adjusted_size, new_version_number);`

Pointer manipulation	Pointer operations such as array element access by adding pointer and index value still work
	`adjusted_array_ptr = (my_array*)`
	`  adi_get_version(array_ptr, adjusted_array_size, my version_number);`
	`(adjusted_array_ptr + 2)->value = 100; // set the third array element`
	`// structure value field to 100`

Custom Memory Allocator

More Information

- Fully documented example in SSM cookbook
  - http://swisdev.oracle.com -> Resources
- Using Application Data Integrity and Oracle Solaris Studio to Find and Fix Memory Access Errors
  - https://community.oracle.com/docs/DOC-912448
- Custom Memory Allocators and the discover SSM Library
  - https://docs.oracle.com/cd/E60778_01/html/E60755/gphwb.html

ADI Caveats

- 64-bit processes only
- Performance impact
  - Negligible for the default disrupting traps
  - Optional precise traps for store mismatches have a noticeable impact, should only be used for debug
  - Updating versions is negligible
- Normalize pointers before
  - compare
  - arithmetical operations
- ADI has a high probability of catching bugs, but a bad pointer may accidentally have a matching version
- DMA read (write to memory) resets ADI version to 0
  - Impacts userland only if Direct I/O is used

ADI Observability

pmap without/with libadimalloc.so

- ADI not used

```
> pmap -xs `pmap malloc`
2899:   ./malloc
         Address     Kbytes        RSS       Anon     Locked Pgsz Mode   Mapped File
---snip---
FFFFFFFF7F7D0000         16         16         16          -   8K rwx----    [ anon ]
FFFFFFFF7F7D4000          8          -          -          -    - rwx----    [ anon ]
---snip---
```

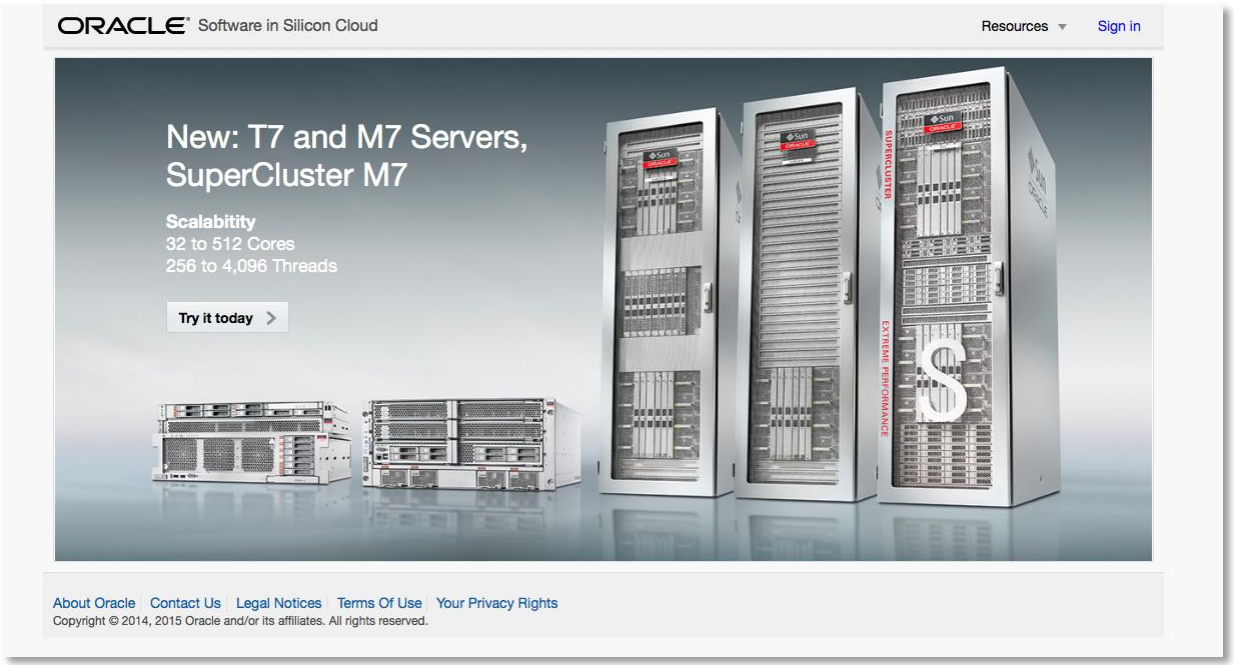
- ADI “active”

```
> pmap -xs `pmap malloc`
2903:   ./malloc
         Address     Kbytes        RSS       Anon     Locked Pgsz Mode   Mapped File
---snip---
FFFFFFFF7DCF0000        256        256        256          -  64K rwx--i-    [ anon ]
FFFFFFFF7DD40000        320        320        320          -  64K rwx--i-    [ anon ]
---snip---
```

Oracle Software In Silicon Cloud

Opening up to broader set of developers

- Online Click through agreement
- Free for OPN partners
- SPARC Enterprise Developers
- University Researchers



http://SWiSdev.Oracle.com

ORACLE

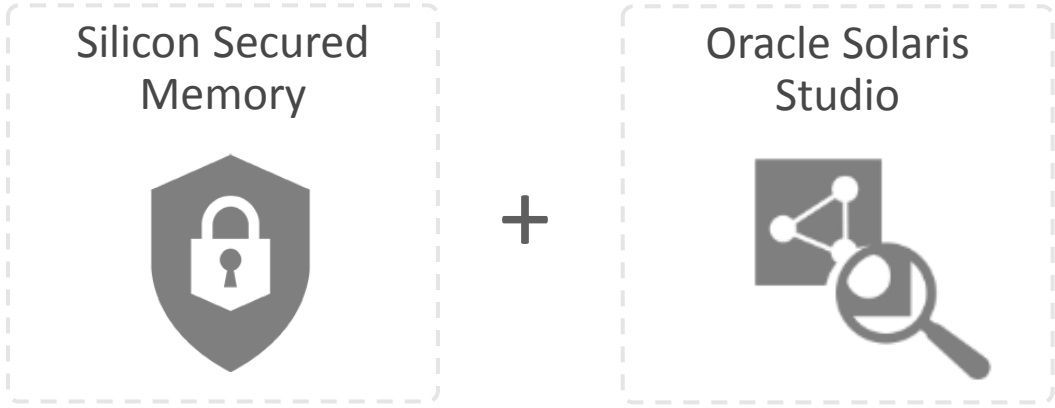
How You Can Use Silicon Secured Memory

- Enable your existing software – No need to recompile!
  - Check application binaries with Solaris Studio 12.4 / 12.5 Beta
  - Link with Solaris libraries – e.g., *malloc()* enhanced with ADI: *libadimalloc*
  - Certify on your test environment
- Develop your applications with Silicon Secured Memory
  - C/C++ 64-bit code, Solaris ADI API
  - Comprehensive tools available with Solaris Studio 12.4 / 12.5 Beta
- Run applications that are enabled with Silicon Secured Memory (examples):
  - Oracle Database 12c (12.1.0.2) uses Silicon Secured Memory in SGA
    - 12.1.0.2 Readme: 2.4 Data Analytics Accelerators on SPARC for Oracle Database Overview
  - ISV software that has been developed with Silicon Secured Memory

Real World Experience

A Case Study

- Large enterprise app with heavy use of memory intensive processing
- Time to value for SPARC M7
  - **4 cross platform** bugs tagged in 2 days
  - **180x faster** bug identification
    - Other memory validation tool: 3 hours
    - Silicon Secured Memory and *Discover*: 1 minute



Integrated. Simple. Fast.

The M7 Microprocessor Can Protect the Entire Cloud

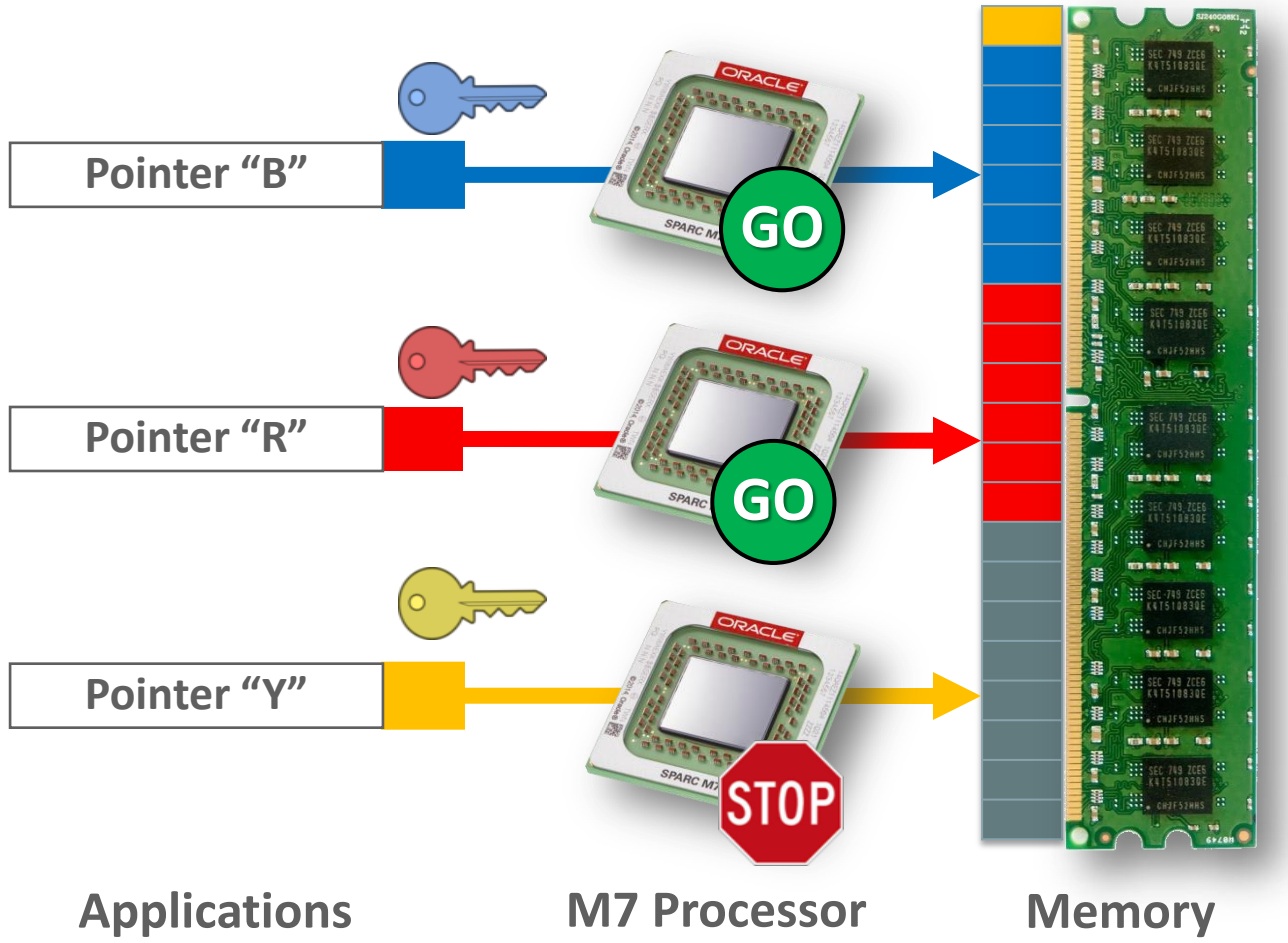
Even if 90% of the Microprocessors are not M7s

- Even a few deployed M7 systems can detect an attack on the entire compute cloud
- Once an attack is discovered, the other unprotected systems then can be patched

Oracle M7

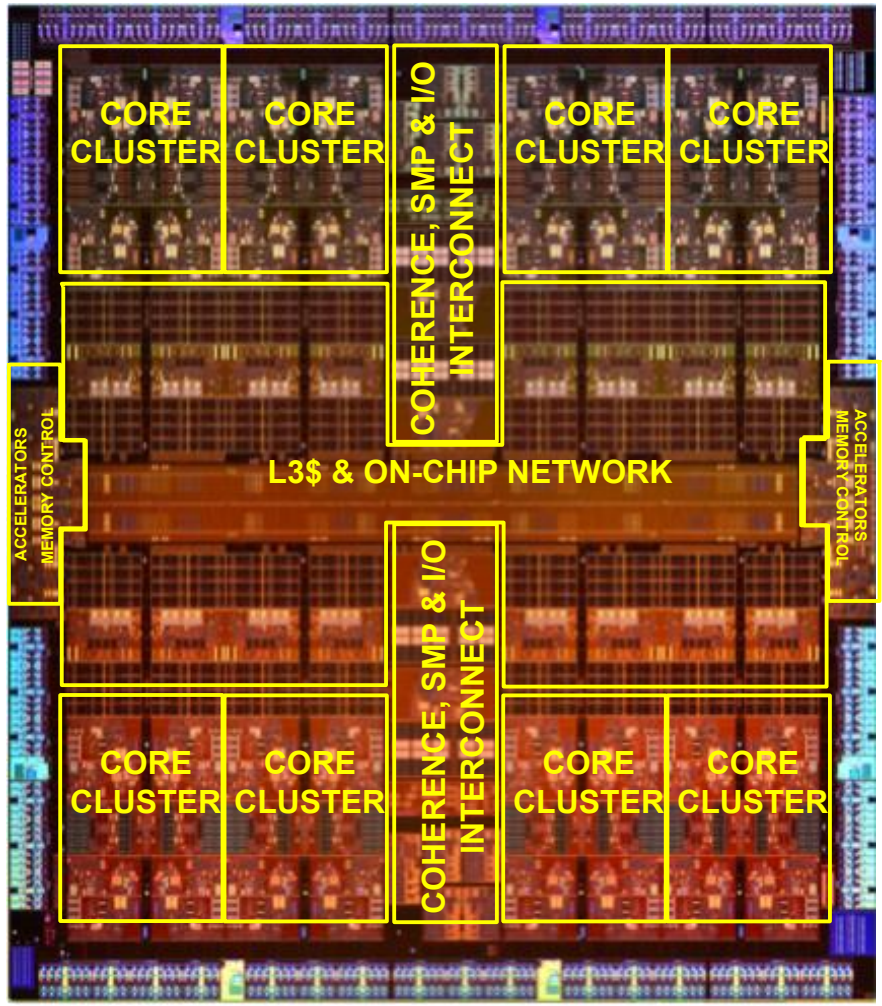
Silicon Secured Memory

- **Protects data in memory**
- Hidden “color” bits added to *pointers* (key), and content (lock)
- Pointer color (key) must match content color or program is aborted
  - Set on *memory allocation*, changed on *memory free’*
  - Protects against *access off end of structure*, *stale pointer* access and malicious attacks
- **Extremely efficient for software development**



Advancing the State-of-the-Art

M7 Microprocessor – World's First Implementation of Software Features in Silicon



- **Always-On Security in Silicon**
  - Near zero performance impact
  - Use in production
  - Silicon Secured Memory (SSM)
    - Application Data Integrity (ADI)
- **High-Speed Encryption**
  - Near zero performance impact
  - 32 Crypto Accelerators
- **SQL in Silicon**
  - High-Speed Memory Decompression
    - "Capacity in Silicon"
  - Primitives to accelerate In-Memory Database Operations
  - 8 Data Analytics Accelerators (DAX) w/ 32 Pipelines
  - Apache SPARK demo at OOW2015

Silicon Secured Memory

More Information

- Silicon Secured Memory Cookbook
  - https://swisdev.oracle.com/_files/ssm-cookbook-page1.html
- Using Application Data Integrity and Oracle Solaris Studio to Find and Fix Memory Access Errors
  - https://community.oracle.com/docs/DOC-912448
- See Raj Prakash's blog @ https://blogs.oracle.com/raj/
  - Oh, no! What Have I Done Now? - Common Types of Memory Access Errors
  - Let's Get The Low Hanging Fruits - Static detection of memory access errors using Previse
  - Solving Trickier Problems - Detecting Dynamic Memory Access Errors Using Discover
  - Surprise! Unexpected Benefits of Hardware Support for Detection of Memory Access Errors

PDF: https://blogs.oracle.com/raj/resource/Silicon-Secured-Memory-Application.pdf

Oracle Solaris Studio

More Information

- History from SPARCWorks to Sun Workshop to Forte Developer to Sun Studio to Oracle Solaris Studio
  - https://blogs.oracle.com/tatkar/entry/studio_release_names_from_the
  - http://www.oracle.com/technetwork/server-storage/solarisstudio/training/index-jsp-141991.html
- on OTN
  - http://www.oracle.com/technetwork/server-storage/solarisstudio/overview/index.html
- Oracle Studio YouTube Channel
  - https://www.youtube.com/watch?v=9gOtXtHfvI4&list=PLKCk3OyNwIzuRh2YsM2MtFAwB_qEWC5Rn&index=3
- Remote Development
  - https://www.youtube.com/watch?v=R8ELRznEoSQ&list=PLKCk3OyNwIzuRh2YsM2MtFAwB_qEWC5Rn&index=24
- Oracle Solaris Studio Learning Library (Screencasts)
  - https://apexapps.oracle.com/pls/apex/f?p=44785:141:10078869691805::NO:141:P141_PAGE_ID%2CP141_SECTION_ID:147%2C1059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