Unsafe Time Handling In Smartphones

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Smartphones are Battery Constrained

Increasing hardware/software functionality

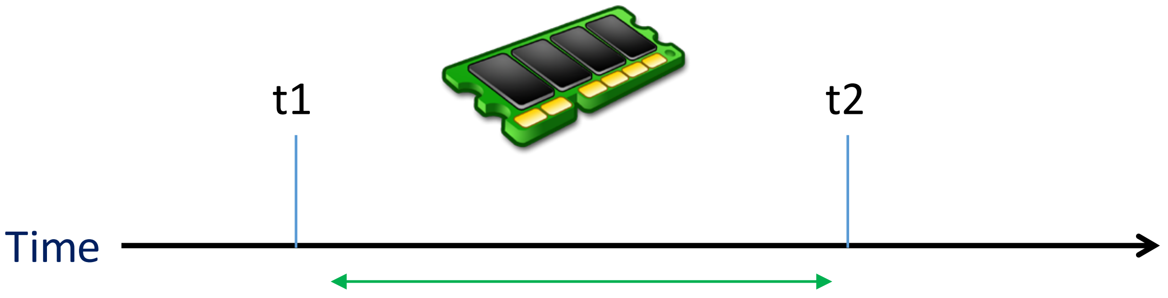
Limited form factor and weight

Paradigm Shift in Power Management: Aggressive Sleeping Policy

- Desktop/Server: CPU Default ON
  - CPU turned off when idle for *long* time
- Smartphones: CPU Default OFF
  - Smartphone OSes aggressively turn off Screen/CPU after *brief* user inactivity
  - Helps increasing standby time period

Time Induced Critical Sections

```
public double do_memcpy ( memcpy_t fn, size_t len, .. ) {
    …                                              6000 MB

    t1 = getTime ( );          0:00

    fn (dst, src, len);

    t2 = getTime ( );          0:03

    t_diff = (t2 – t1);        3

    return len / t_diff;
}                   6000/3 = 2000 MBps
```

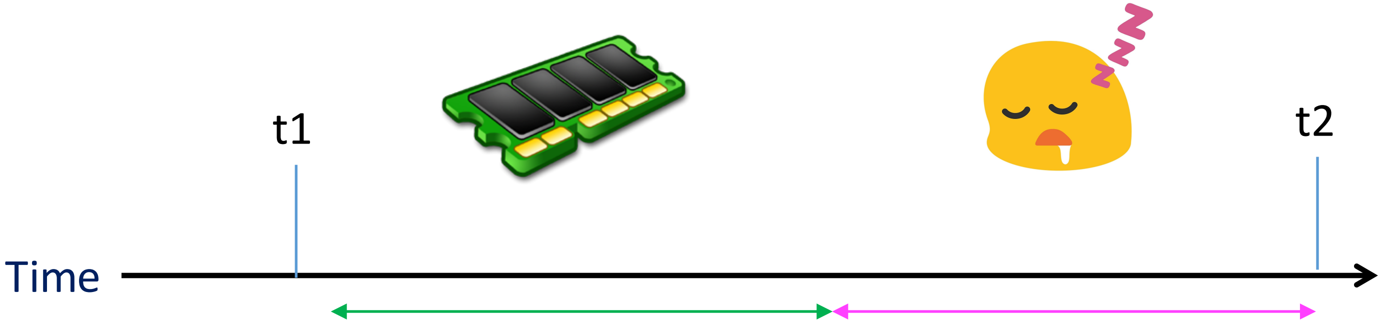


From tools/perf/bench/mem-memcpy.c

Sleep Induced Time Bugs

```
public double do_memcpy ( memcpy_t fn, size_t len, .. ) {
        …
        t1 = getTime ( );          0:00
        fn (dst, src, len);
        t2 = getTime ( );          5:00
        t_diff = (t2 – t1);        300
        return len / t_diff;
}
                 6000/300 = 20 MBps
```

6000 MB



From tools/perf/bench/mem-memcpy.c

Sleep Induced Time Bugs (2)

- SITB happens when the smartphone CPU/SOC is suspended in the middle of a time manipulation
  - Alters intended program behavior
- Hard to reproduce
  - Will only happen when CPU sleeps when the code execution is between time manipulation

"I think it will fix an odd issue I have seen in a log file (apparently was completely off track debugging it). As this very likely is a real world issue, I'd recommend applying the patch to the fixes branch"

– Android kernel developer

Power Control API-- Wakelocks

```
Foo(…){
        wake_lock ( … )
        time manipulation

        wake_unlock ( … )

}
```

- CPU is suspended only after last wakelock is released

Outline

- Sleep Induced Time Bugs
- Categorizing Time Usages and Vulnerabilities to SITB
  - Case 1 : Timed Callback
  - Case 2 : Time Setting
  - Case 3 : Time arithmetic
  - Case 4 : Logging
- Klock Design
- Evaluation

Time Usage In Android

- Collected list of time related APIs exposed at each software layer and grepped them

	Kernel	**Android Framework**	**978 Apps**
Time usages	1072	1737	7798

- Usages belong to four categories
  - Timed Callback, Time setting, Time arithmetic, Logging

Case 1: Timed Callback

- Code wishes to perform a certain task at a future time
  - Register alarm with system specifying a callback function and a time interval

drivers/serial/msm serial.c

```
void msm_serial_clock_request_off(..,  int timeout){
   clk_off_timer.function = msm_serial_clock_off;
   hrtimer_start (clk_off_timer, timeout );
}
```

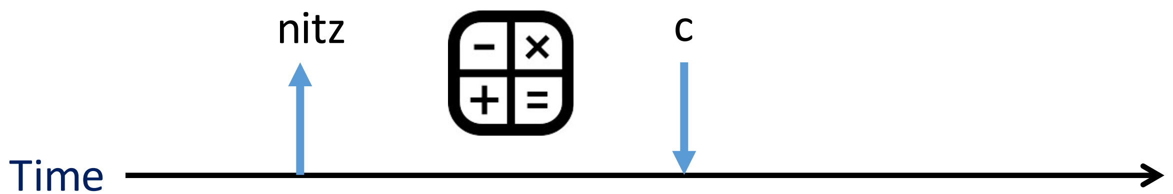
```
msm_serial_clock_off (struct hrtimer timer){
          clk_disable(msm_port->clk);
}
```

- **Vulnerability**: CPU suspension before timer callback finishes alters intended semantics

Case 2: Time setting

- Code updates current system time

```
void setTimeFromNITZString( .. ) {
        nitz = getTime ( );
        /* some processing */
        c = f ( nitz );
        setAndBroadcastNetworkSetTime ( c );
}
```



From com/android/internal/telephony/gsm/GsmServiceStateTracker.java

Case 2: Time setting vulnerability

- Code updates current system time

```
void setTimeFromNITZString( .. ) {
        nitz = getTime ( );
        /* some processing */
        c = f ( nitz );
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}
```
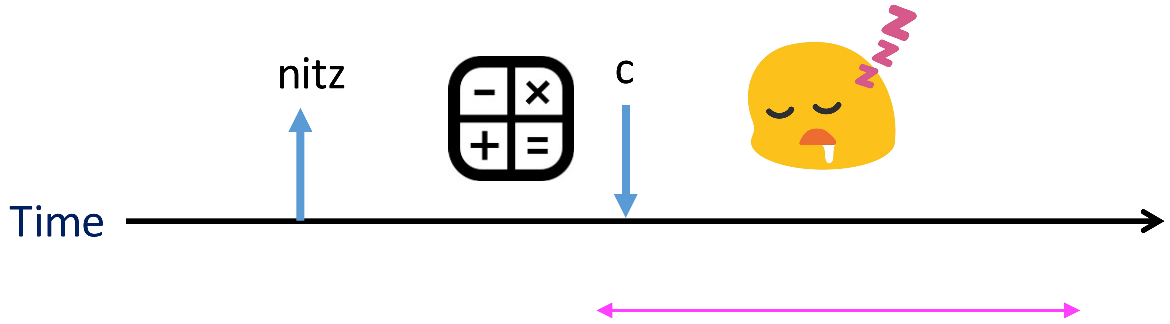



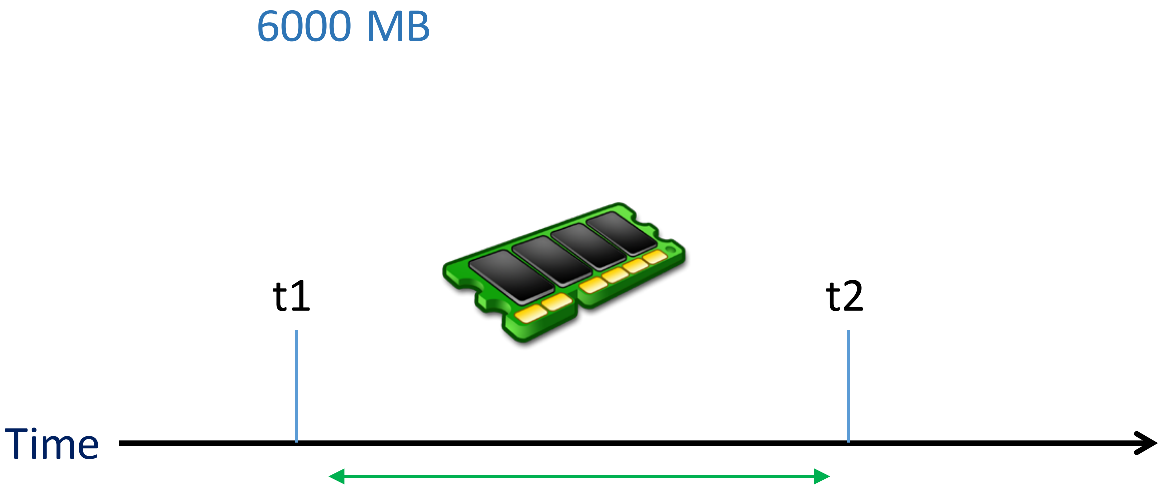
From com/android/internal/telephony/gsm/GsmServiceStateTracker.java

CPU sleeps before setTime would set stale time

Case 3: Time arithmetic

- Code collects two timestamps and performs arithmetic on them

```
public double do_memcpy ( memcpy_t fn, size_t len, .. ) {
        …

        t1 = getTime ( );          0:00

        fn (dst, src, len);

        t2 = getTime ( );          0:03

        t_diff = (t2 – t1);        3

        return len / t_diff;
}                 6000/3 = 2000 MBps
```



From tools/perf/bench/mem-memcpy.c

Case 3: Time arithmetic vulnerability

CPU sleeps between obtaining two timestamps

```
public double do_memcpy ( memcpy_t fn, size_t len, .. ) {
        …
        t1 = getTime ( );
        fn (dst, src, len);
        t2 = getTime ( );
        t_diff = (t2 – t1);
        return len / t_diff;
}
```

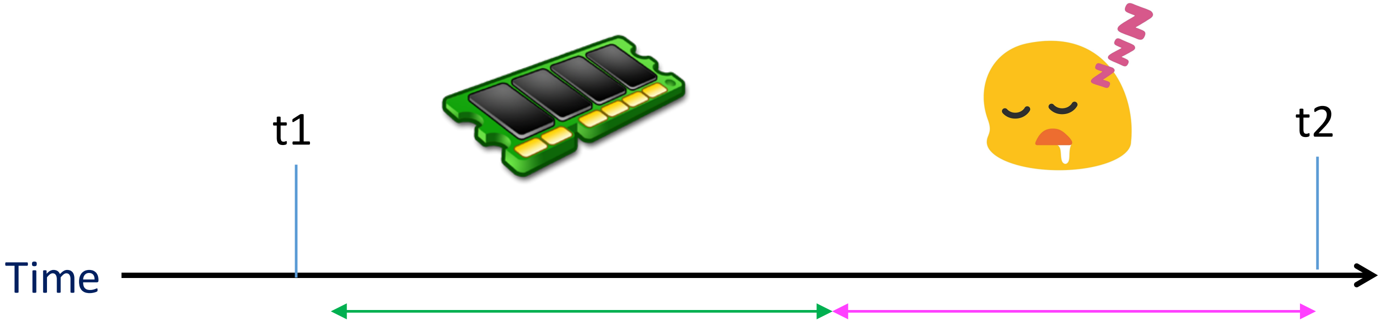
6000 MB

0:00

5:00

300

6000/300 = 20 MBps



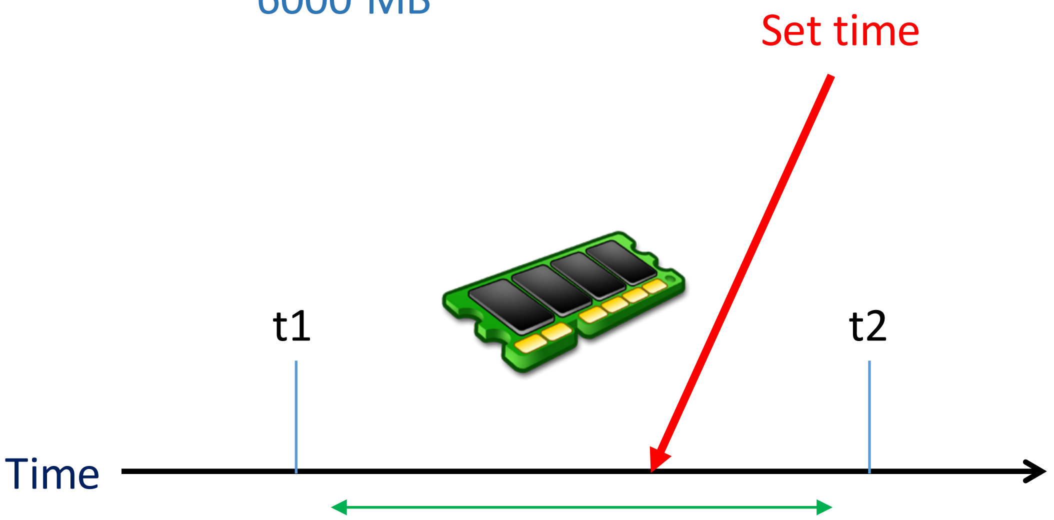
From tools/perf/bench/mem-memcpy.c

Case 3: Time arithmetic vulnerability (2)

Time is set between obtaining two timestamps

```
public double do_memcpy ( memcpy_t fn, size_t len, .. ) {
        …
        t1 = getTime ( );          1:00
        fn (dst, src, len);
        t2 = getTime ( );          0:00
        t_diff = (t2 – t1);        -60
        return len / t_diff;
}                6000/-60 = -100 MBps
```

6000 MB



From tools/perf/bench/mem-memcpy.c

Case 4: Time logging

- Code obtains current time and logs it in conjunction with some event
  - Usually for postmortem debugging

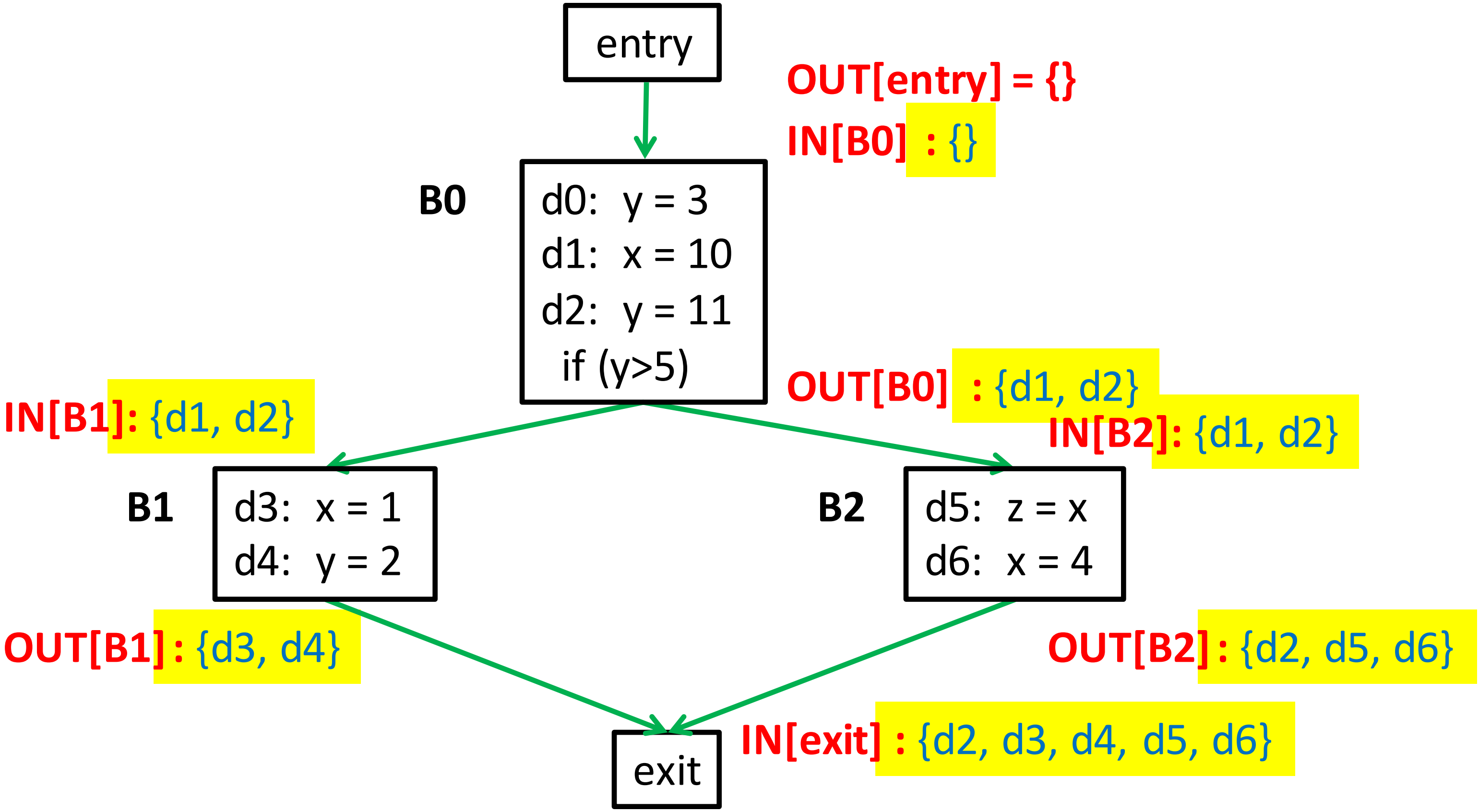
- **Vulnerability**: CPU suspension in between event and its timestamping will result in an incorrect timestamp being logged for the event.

Overview

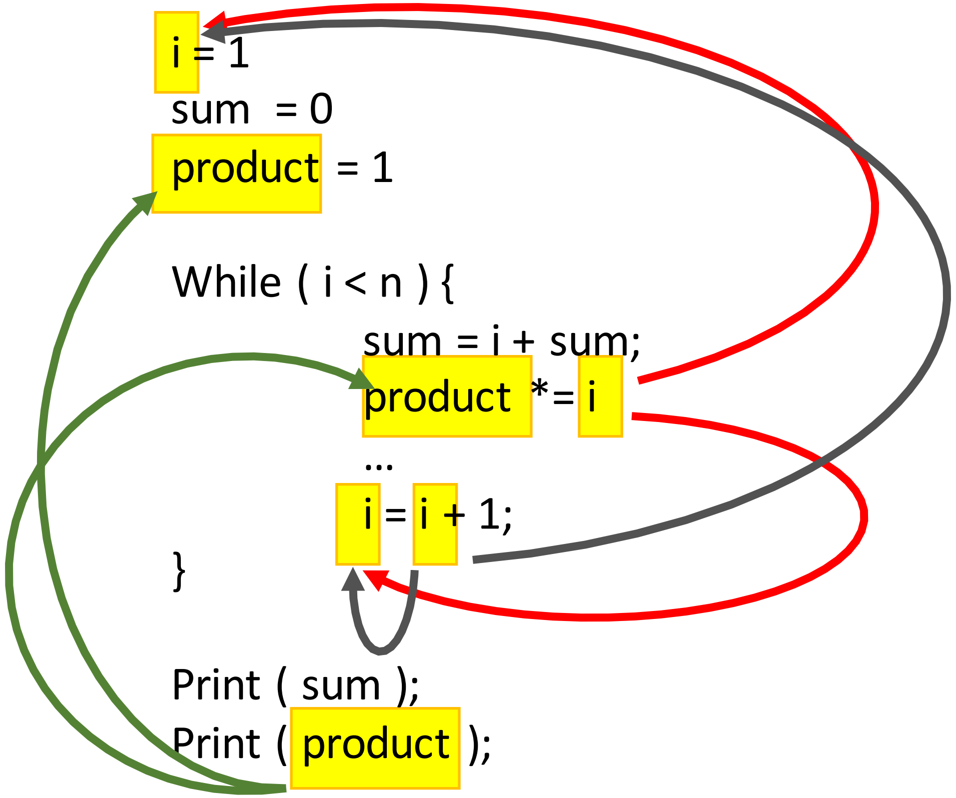
- Sleep Induced Time Bugs
- Categorizing Time Usages and Vulnerabilities to SITB
- Klock Design
    - Primer on Reaching definition, UD and DU chains
    - Identifying Protected Statements
    - Identifying Time Critical Sections
    - Implementation
- Evaluation
- Conclusion

Reaching Definition DataFlow problem

```
y = 3;
x = 10;
y = 11;

if( y > 5 ) {
    x = 1;
    y = 2;
} else {
    z = x;
    x = 4;
}
```



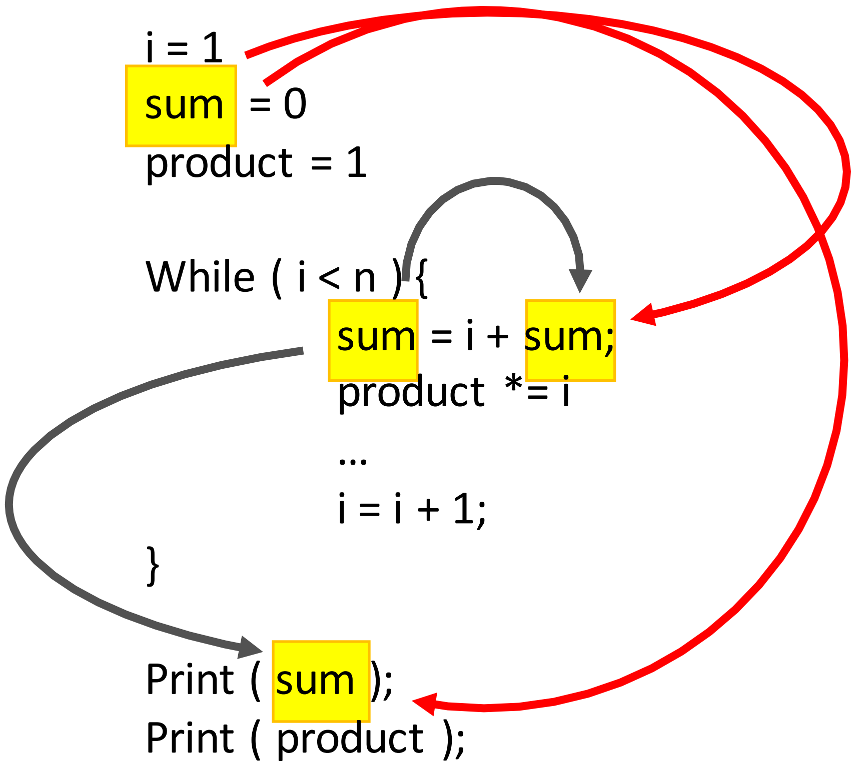
Use-Def (UD) Chains



Links each use of variable x to DEF which reach that use

Closure: Recursively following UD chains show all DEFs that impact 1 variable use

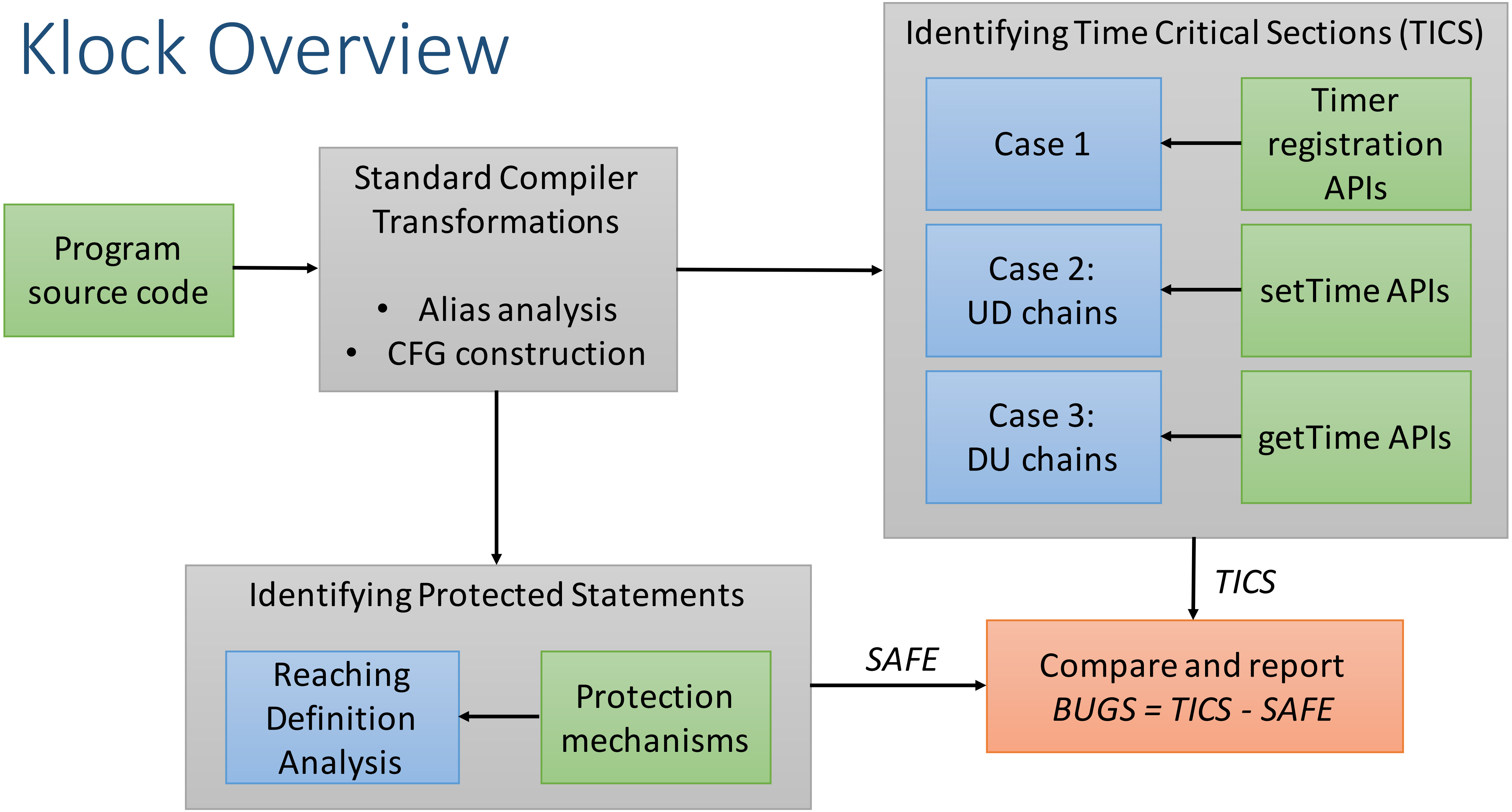
Def-Use (DU) Chains



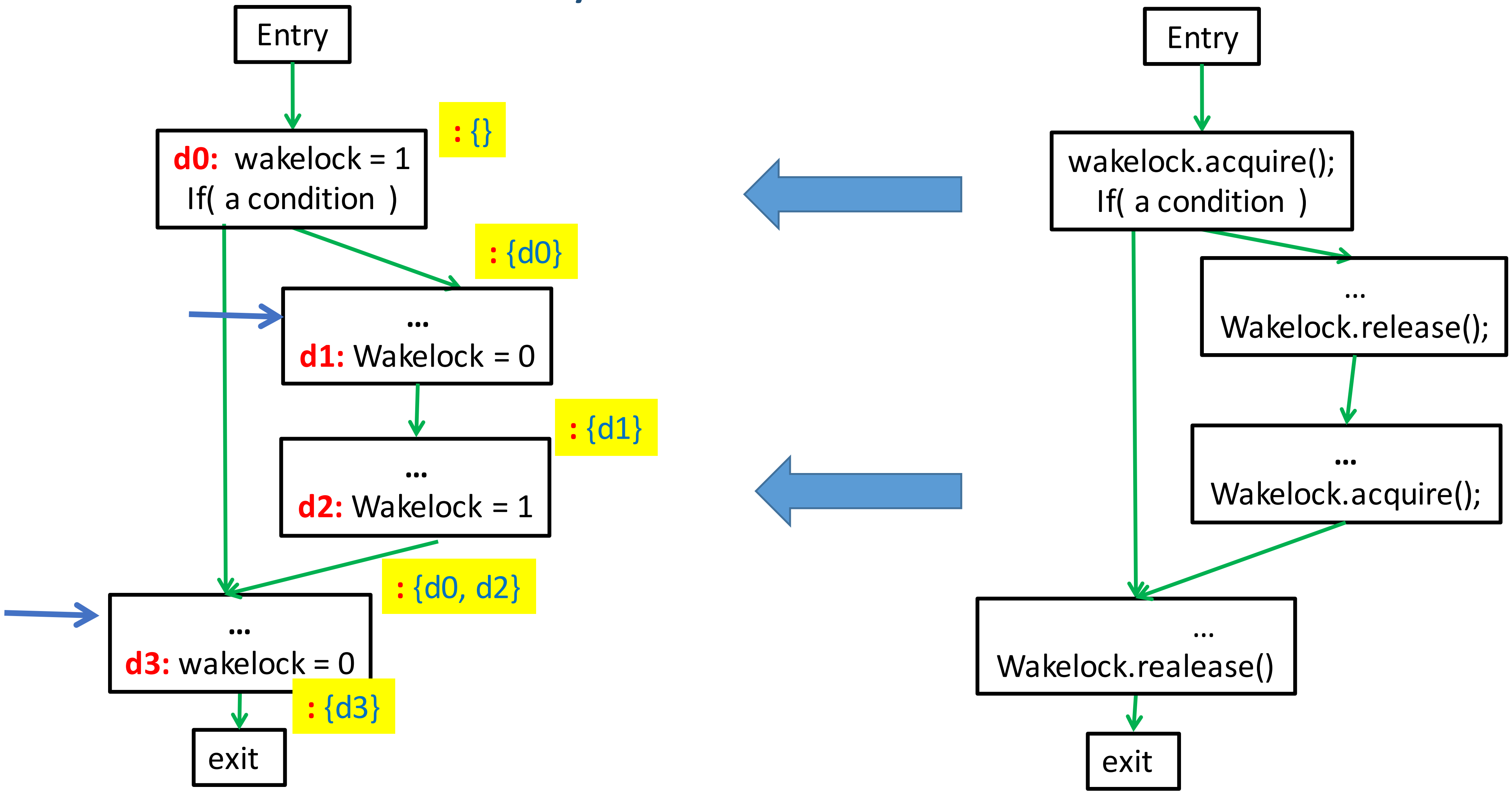
Links each definition of variable x to those USE which that definition can reach.

Closure: Recursively following DU chains show all USEs impacted by 1 definition

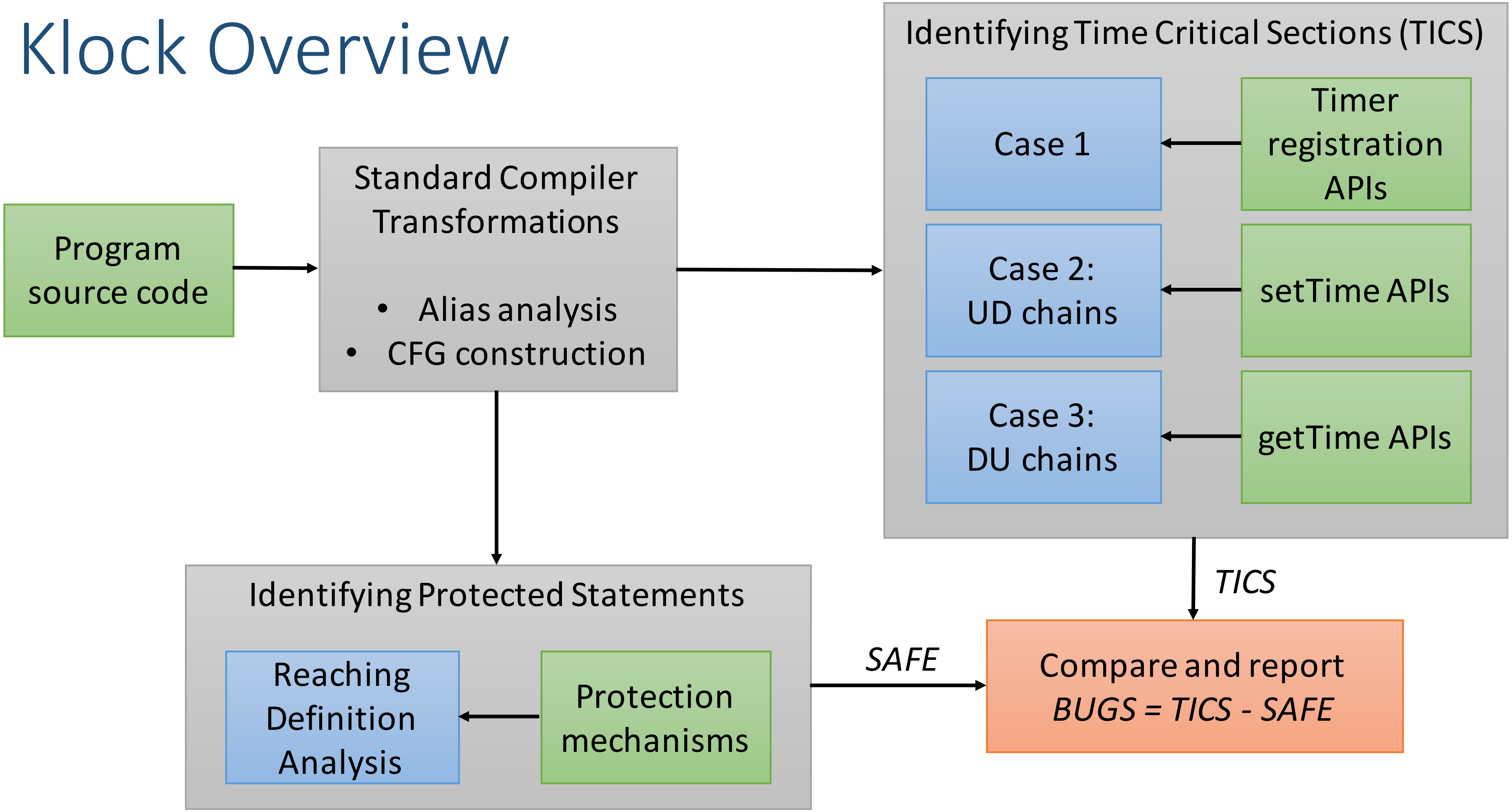
Klock Overview



RDA to Identify Protected Statements



Klock Overview



Identifying Time Critical Section Case 1: Timer Callback

For every timer registration site

- Find callback function target
- Conservatively add callback function to TICS

```
void msm_serial_clock_request_off(..,  int timeout){
  clk_off_timer.function = msm_serial_clock_off;

  hrtimer_start (clk_off_timer, timeout );
}
```

```
msm_serial_clock_off (struct hrtimer timer){
        clk_disable(msm_port->clk);
}
```

TICS

Identifying Time Critical Section
Case 2: Time Setting

```
void setTimeFromNITZString( .. ) {
    nitz = getTime ( );
    /* some processing */
    c = f ( nitz );
    setAndBroadcastNetworkSetTime ( c );
}
```

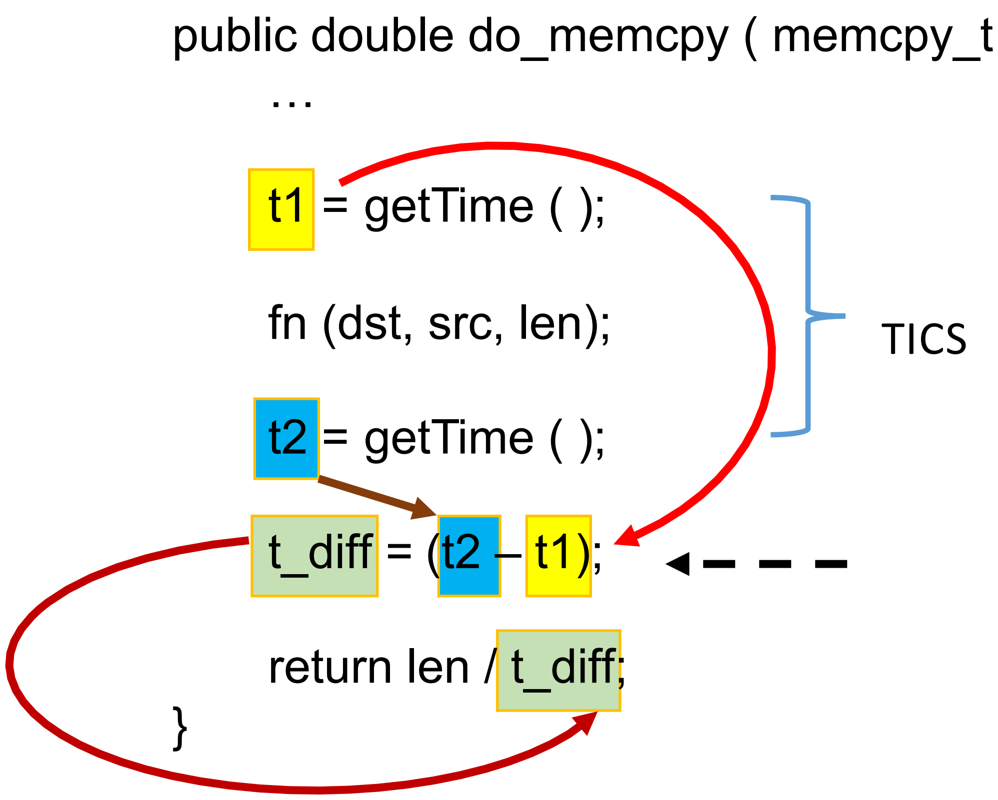
TICS

For all statements, where time is set

- Recursively find DEFS using UD chains
- Add all paths from DEFS to set time into TICS

From com/android/internal/telephony/gsm/GsmServiceStateTracker.java

Identifying Time Critical Section
Case 3: Time Arithmetic



For all definitions that get time

- Find closure of USES using DU chains

If a statement has variables from two different closures (t1, t2)

- Must be arithmetic between t1, t2
- Add all statements between getting t1 and getting t2 to TICS

Implementation

- Built on LLVM compiler infrastructure
  - 1 custom pass to build call graph
  - 4 custom passes for identifying protected statements and identifying TICS (case 1,2, 3)
- ~5 KLOC
- Available at http://github.com/klock-android

Overview

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- Categorizing Time Usages and Vulnerabilities to SITB
- Klock Design
- Evaluation

Evaluation

- Ran Klock on 5 different kernel versions
  - Nexus 1, Nexus 7, Nexus 10, Nexus S and x86 (with wakelocks enabled)
- Found 63 bugs
  - 4 timed callback bugs, 0 time setting bugs, 59 time arithmetic bugs
  - 14 have been fixed, 7 files have been removed in newer kernel versions
  - Out of 42 remaining, 7 developers replied so far confirming the bugs

Bugs (63) breakdown

- Correctness related bugs (18)
  - 6 drivers incorrectly measure pulse width hence reading wrong received data
  - 5 radio drivers incorrectly measure clock rate necessary to decode the incoming data
  - 7 other miscellaneous bugs
- Performance related bugs (15)
  - 8 drivers spin for an extended period of time leaving device unusable
  - 4 code locations call sleep for a long time
  - 3 drivers keep their devices on longer than necessary wasting energy
- Benchmark bugs (30)

False Positives

- 106 False positives
- Suspension does not affect program semantics
  - driver generates a random number using timer arithmetic
- System calls
  - System calls (eg sys_settime) are just wrappers of actual time setting APIs and do not have suspension prevention mechanism

Conclusion

- Sleep Induced Time Bugs
  - Time manipulation form Time Critical Sections
  - CPU suspension during Time Critical Sections lead to the bugs
- Time is widely manipulated in Android Ecosystem
  - Timed callback, Time setting, Time arithmetic and Logging
- Klock
  - Static checker built using reaching definition analysis, UD/DU chains
  - Found 63 bugs in the kernel
  - http://github.com/klock-android