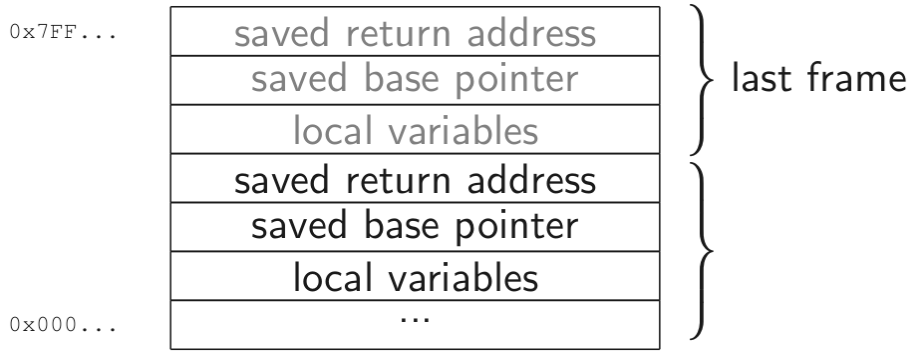
Memory safety

- spatial violation
  - buffer overflow/read
  - out-of-bounds reads
  - null pointer dereference
- temporal violation
  - use after free
  - double free
  - use of uninitialized memory
- stack frame layout

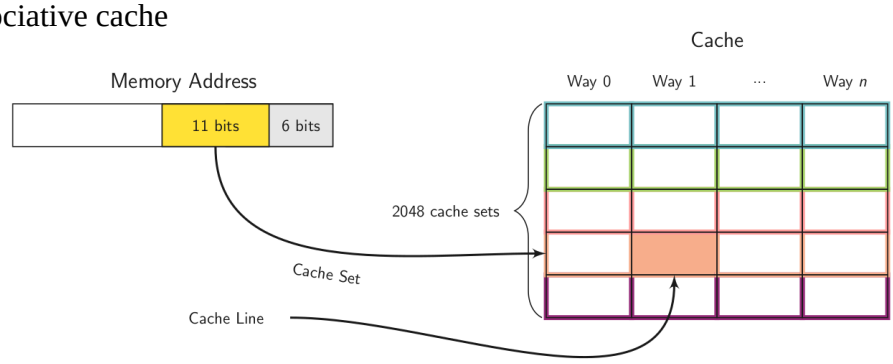


  -
- prevent (some) buffer overflows with
  - stack canary
    - random number stored below stack frame and buffer
    - before returning check for overwrite
  - safe and unsafe stack
    - store buffers on unsafe stack
  - ASLR
    - randomizes location of memory
    - requires large enough randomization range
    - addresses must not be leaked
- control flow integrity CFI
  - Control-flow graph must be correctly constructed
  - Function pointers cannot be protected if destination set is large
  - Some functions (e.g., library functions) have many call locations and therefore return locations
  -

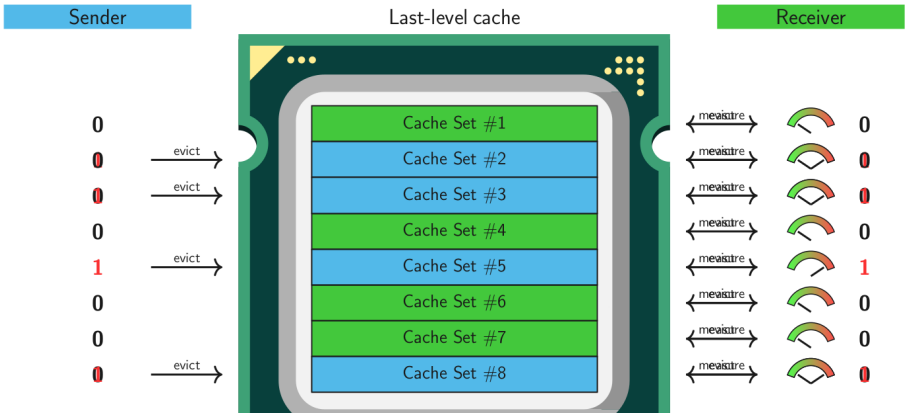
Side-channel attacks

- passively observe physical properties
- information leakage through side-effects
  - power consumption

  - execution time
    - preventable through constant runtime and control flow
  - CPU caches
    - fast on cache hit, slow on miss
- set associative cache



  -
  - each memory address has a designated cache set to be cached in
- Flush+Reload
  - requires shared memory
  - determine which memory locations have been accessed by measuring the time to access it
    - attacker flushes cache line
    - victim might access memory locations of this cache line
    - attacker reloads the cache line and measures the time
      - short => victim accessed the location
  - keystrokes can be retrieved because they cause code execution in shared library (e.g. libgdk)
- covert channel
  - two processes communicate over secret channel



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transient execution attacks

- meltdown
  - read data at any address using out-of-order execution

```
char data = *(char*) 0xffffffff81a000e0;
array[data * 4096] = 0;
```

  - combined with Flush+Reload
  - index of cache hit reveals data
  - preventable with KAISER/KPTI
    - unmap kernel pages in user space
    - kernel addresses are no longer present
- NG-Foreshadow
  - leak data from L1 cache of host into VM
- spectre
  - exploit control flow predictions
  - speculative execution runs

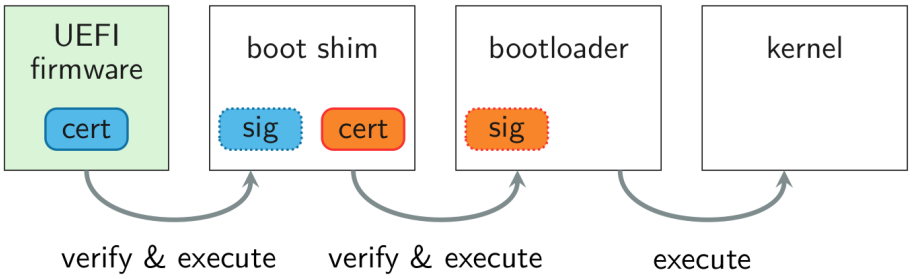
```
if (x < array1_size)
    y = array2[array1[x] * 256];
```

    - array1 is a valid buffer
    - x is a way too big and causes an overread into the victim's memory
    - array2 is uncached shared memory
  - crashes because it accesses not allowed memory
    - still accesses the page (speculative execution) and rollbacks the operation
    - accessing page at array1[x] causes a cache hit

Fault attack

- actively manipulate device to induce faults
- Row hammer
  - accesses to nearby DRAM rows cause cell to leak energy which may cause bit flips
- Glitching/Skipping attacks
  - may corrupt data/skip instructions
- Undervolting
- countermeasures
  - detect anomalies
    - active fine wire meshes across IC
    - power surge/temperature/light sensors?
  - double execution
    - unlikely to produce same fault twice

Sandboxing and Isolation

- Principle of Least Privilege
  - »Every program and every privileged user of the system should operate using the least amount of privilege necessary to complete the job.«
  - e.g. x86 Protection Rings
  - drivers have higher privileges than user-space applications
    - only accept drivers signed by trusted vendor
    - root attacker cannot inject code into kernel
- Secure Boot
  - UEFI ROMs, boot loader, kernel must be signed
  - public key in firmware to verify signatures
  - execute after verification
  - 

- Supervisor Mode Access/Execution Prevention
  - prevent access to user-space data
  - prevent execution of user-space code
  - opposite of KAISER/KPTI
- Sandboxing
  - restricted environment to execute program in
  - resources strictly controlled
    - own filesystem
    - no network connection
    - limited memory
    - limited CPU time
    - …
  - Language-Level-Sandboxing
    - restrict untrusted code on the language level
      - e.g. JavaScript
    - no dangerous functionality (I/O, syscalls, …)
      - ask user for permission if needed
    - interpreter
    - eBPF verifies certain properties before executing code
      - termination

        - no loops/recursion
            - halting problem
        - jumps may not form loops
        - only allowed functions
    - Rule-based Execution
        - define what an application is allowed to do
            - white/blacklists
        - e.g. seccomp
        - good policies are hard to create but secure and efficient
    - Container
        - OS-level virtualization
        - isolated user-space instances
        - each container is assigned resources
            - memory
            - folder
            - …
        - only see assigned resources
        - shared OS, separate libraries/dependencies
        - Control Groups?
        - Namespaces
            - isolate system resources between processes
                - cannot see other processes
                - own mount
                - own network stack
                - …
    - Virtualization
        - no shared kernel since process runs in own OS
        - emulate entire system => massive overhead
            - bare metal
                - run directly on hardware
            - hosted
                - on top of host OS
        - VM escape
            - access to host and other VMs
- Isolation
    - isolate application from system
        - trusted application on untrusted system
    - applications

    - sensitive data
    - distrust against cloud provider
    - intellectual property
    - rights management
- Trusted Computing Base TCB
    - CPU and firmware usually
    - kernel and system programs usually too
        - protected by protection rings
- Trusted-Execution Environment
    - secure area within CPU
    - guarantee integrity and confidentiality for code + data
    - still shared hardware
    - small overhead
    - CPU is the only TCB
    - memory encrypted and inaccessible to OS
    - does not protect against side channel attacks
- Hardware Isolation with Hardware Security Modules HSM
    - external, dedicated hardware
        - nothing shared
    - protects high-value cryptographic keys
    - crypto processor for
        - key generation/management
        - signatures
        - data en/decryption
        - strong RNG
        - secure timestamp