CTSRD

CRASH-worthy Trustworthy Systems Research and Development

Is it time to replace mmap?

A history of virtual address management (and a proposal for the future)

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BSDCan 2018, Ottawa, Canada

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SRI International

University of Cambridge

Memory

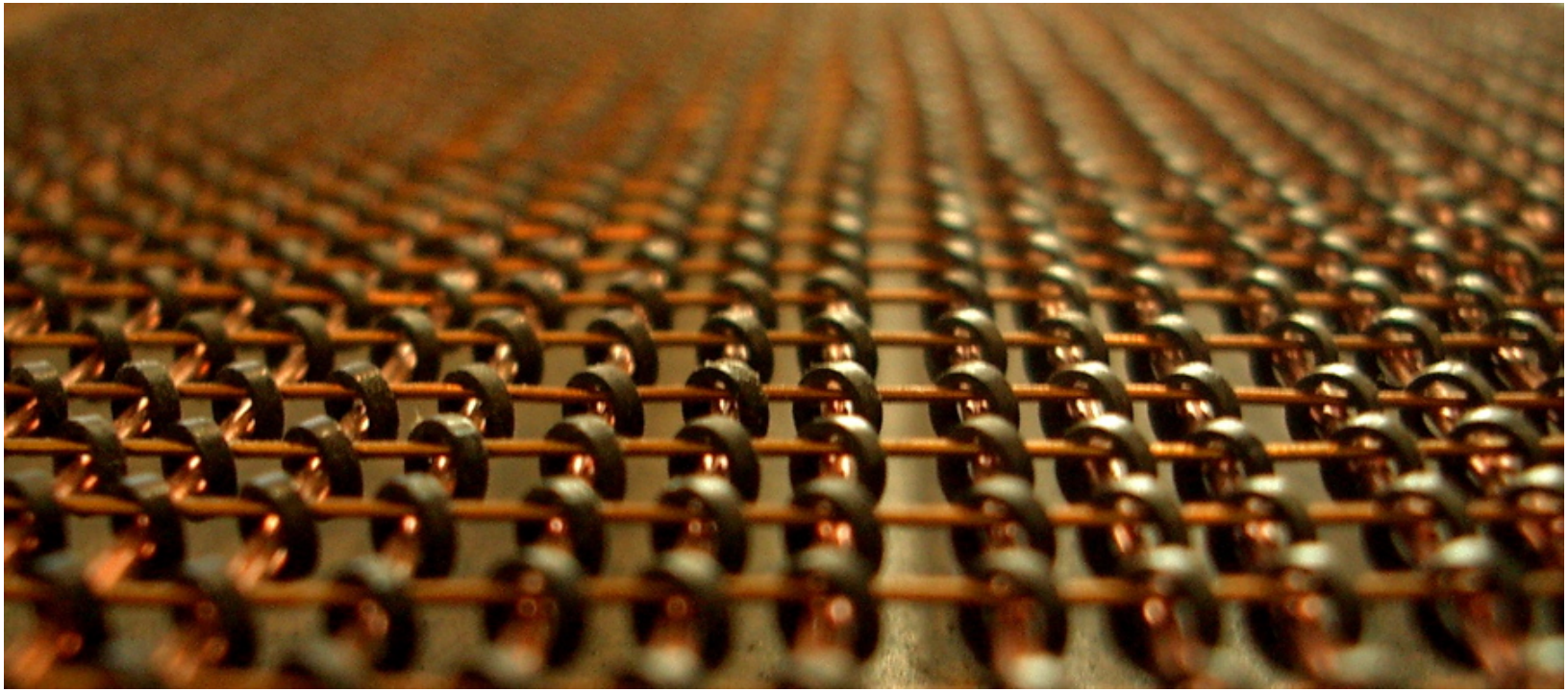
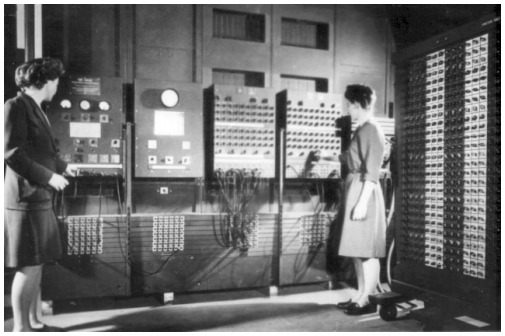


Photo credit: Steve Jurvetson from Menlo Park, USA

A bit of computer history



ENIAC c.1945

EDSAC c.1949

PDP-11
c.1970

1386 1985

Baby c.1948

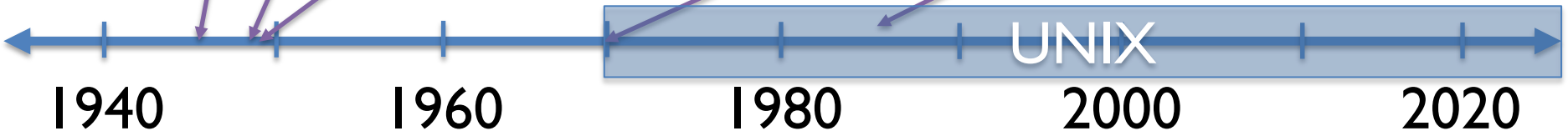
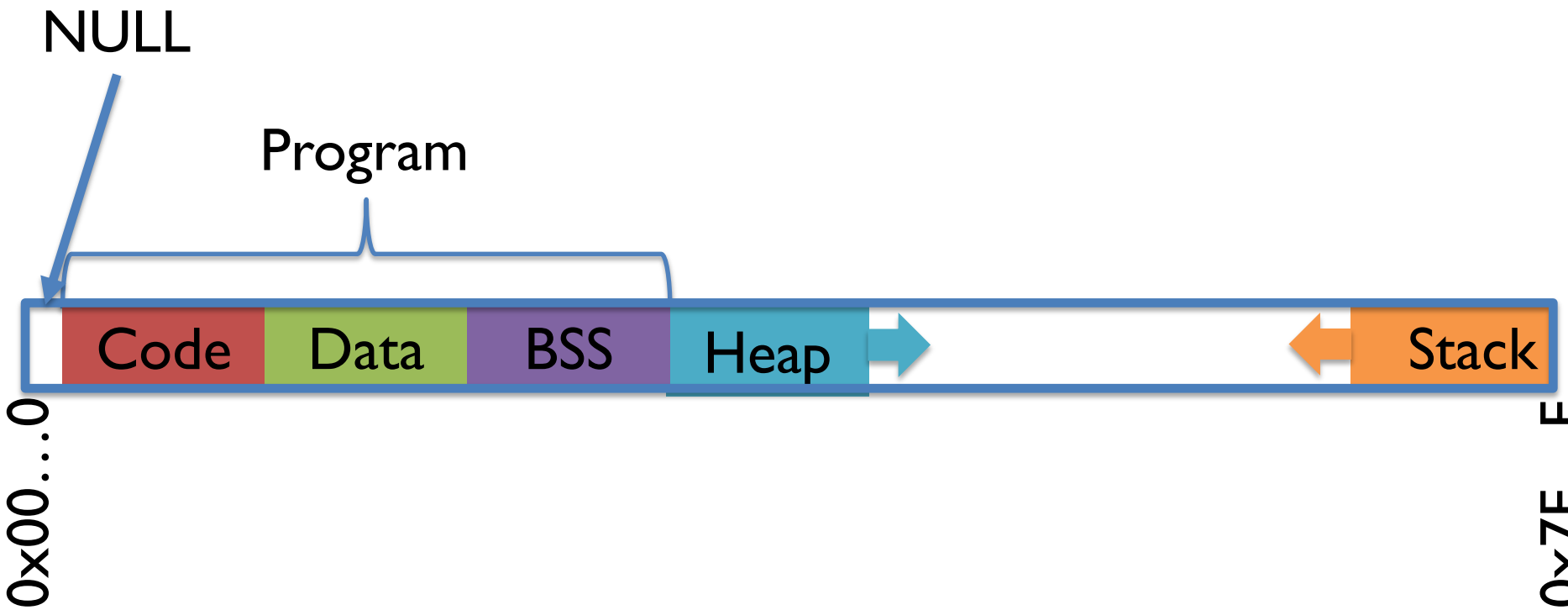


Photo sources:
ENIAC: Two women operating ENIAC - U.S. Army Photo
EDSAC: EDSAC I, R.Hill operating - Copyright Computer Laboratory, University of Cambridge. Reproduced by permission. PDP-11: DEC - PDP-11- Ken Thompson and Dennis Ritchie – Courtesy Computer History Museum

Process address space



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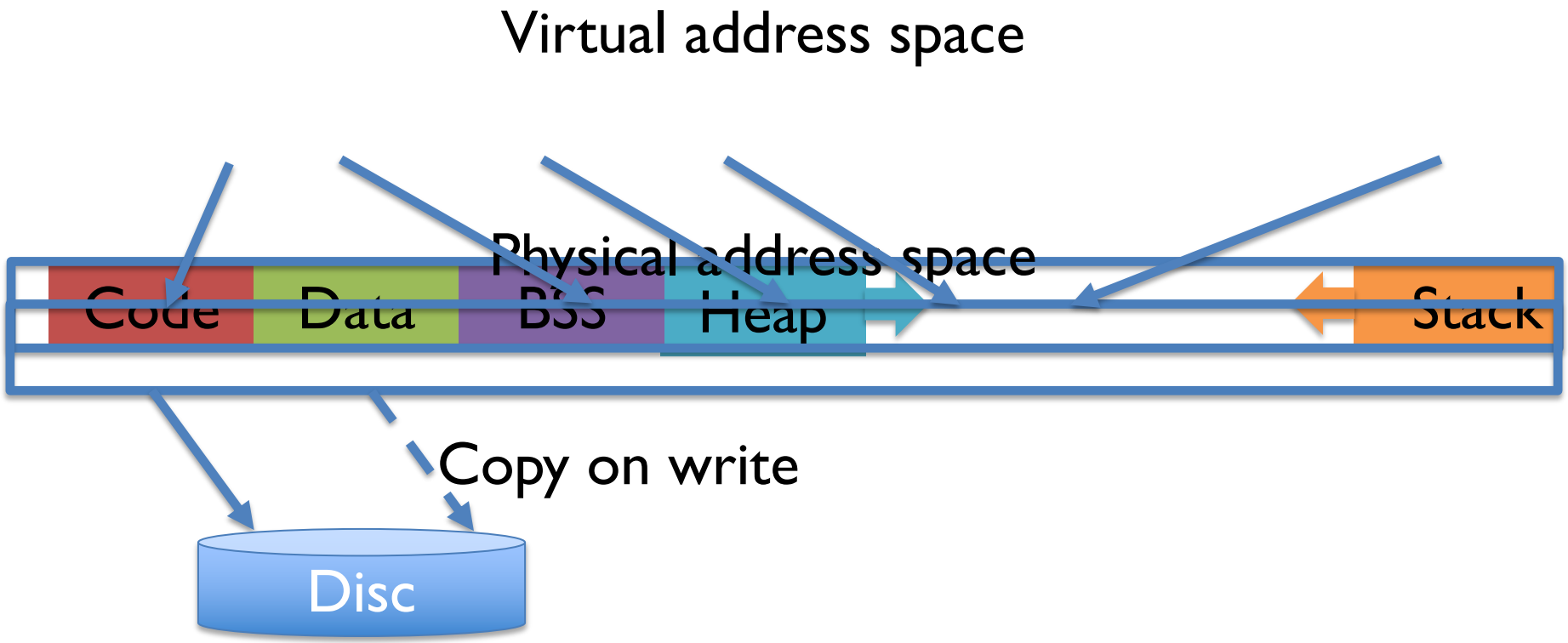

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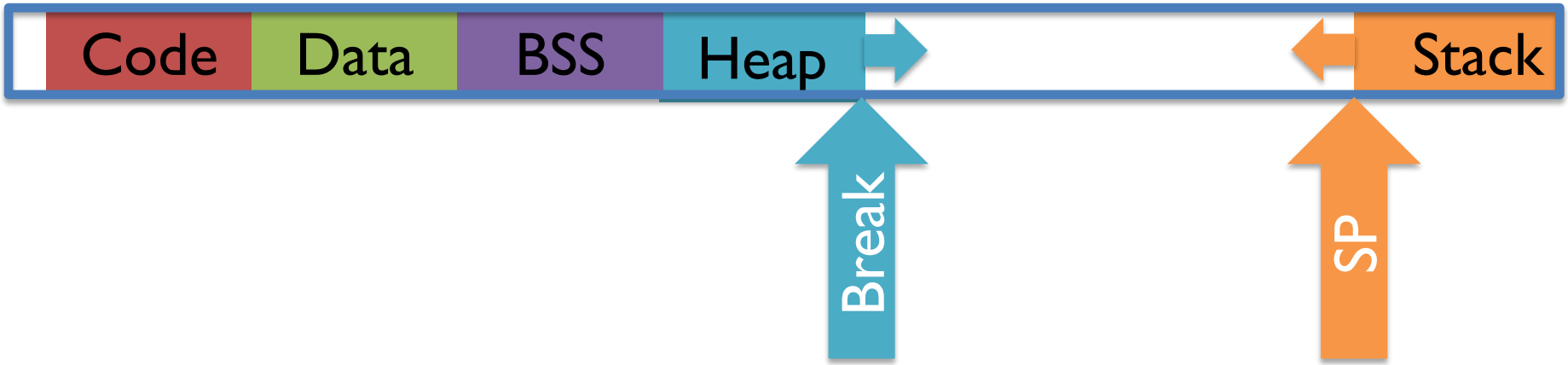
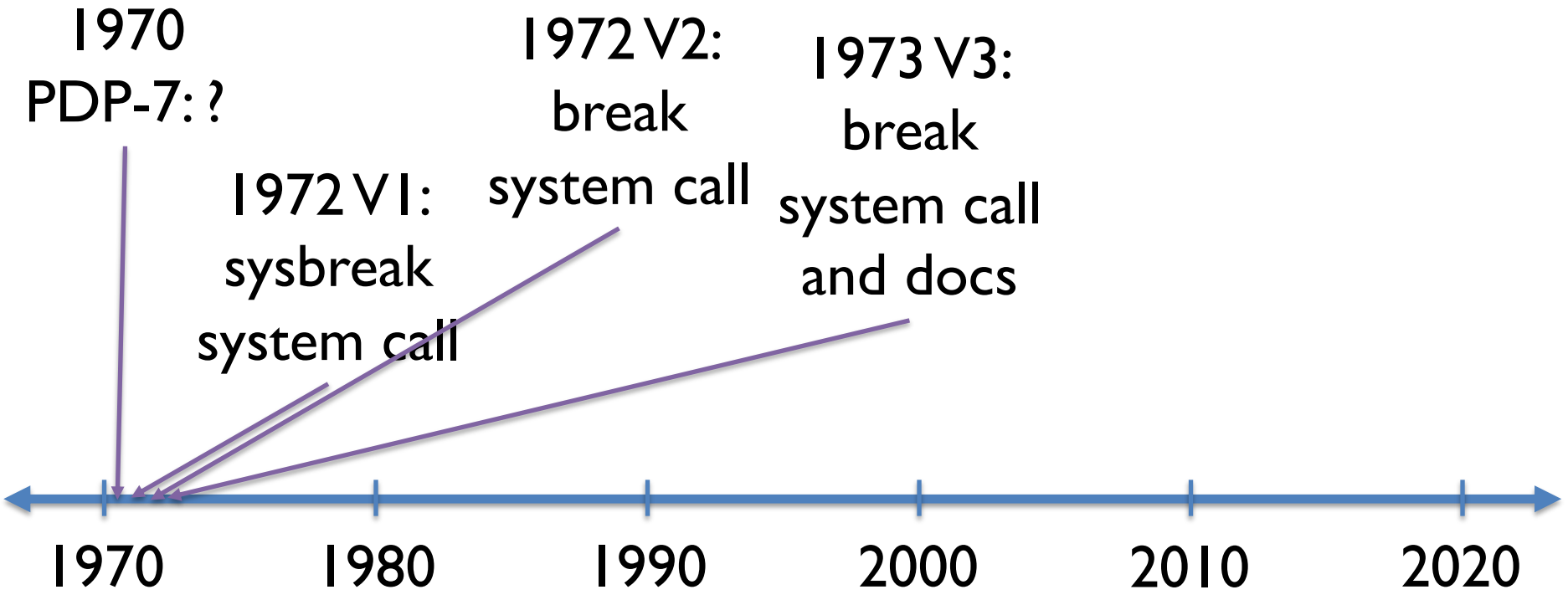


UNIX and BSD

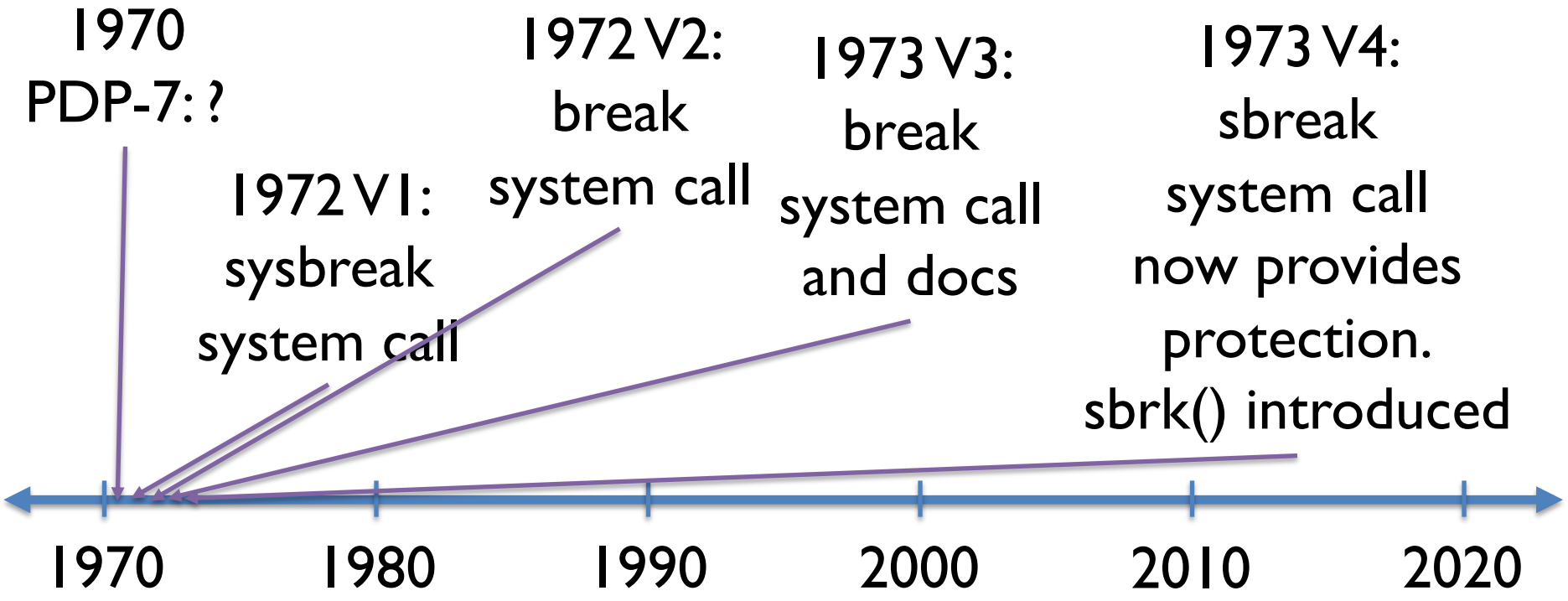


break.2 (V3 Unix)

break sets the system's idea of the highest location used by the program to addr.

Locations greater than addr and below the stack pointer are not swapped and are thus liable to unexpected modification.

UNIX and BSD



break.2 (V4 Unix)

Break sets the system's idea of the lowest location not used by the program to *addr* (rounded up to the next multiple of 64 bytes).

Locations not less than *addr* and below the stack pointer are not in the address space and will thus cause a memory violation if accessed.

break.2 (V4 Unix) (cont)

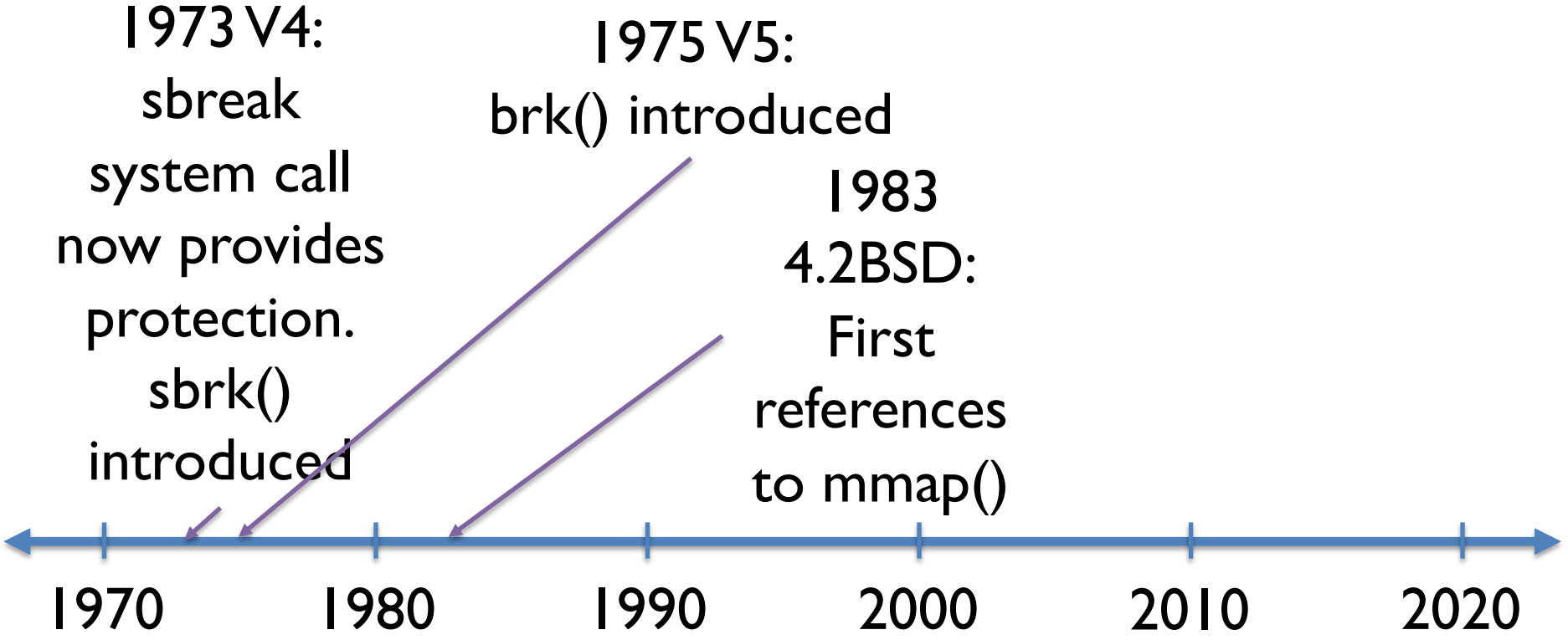
```
char *sbrk(incr)

…
```

From C, the calling sequence is different; *incr* more bytes are added to the program's data space and a pointer to the start of the new area is returned.

break.2 (V4 Unix) (cont)

When a program begins execution via *exec* the break is set at the highest location defined by the program and data storage areas. Ordinarily, therefore, only programs with growing data areas need to use *break*.

UNIX and BSD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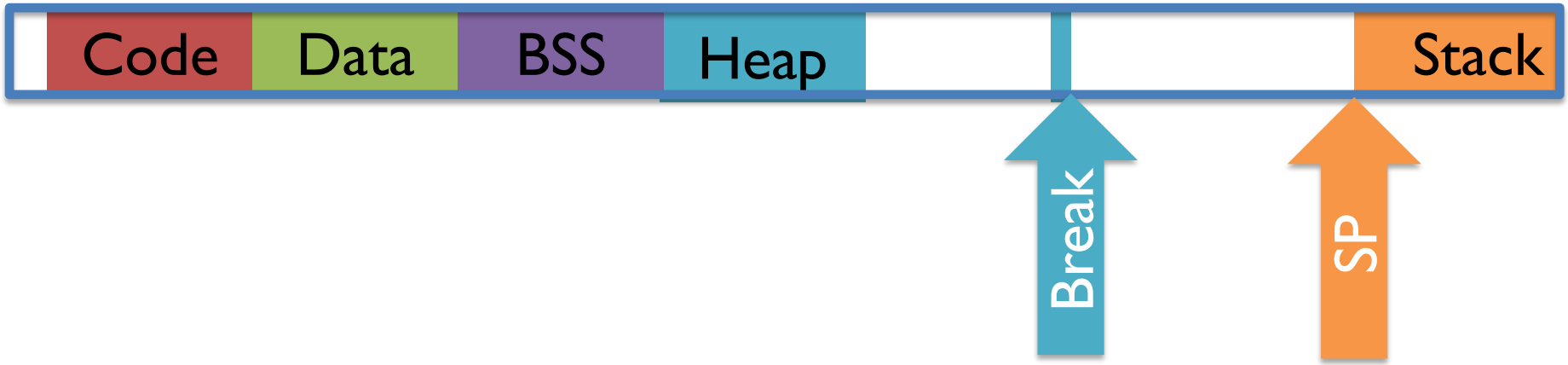
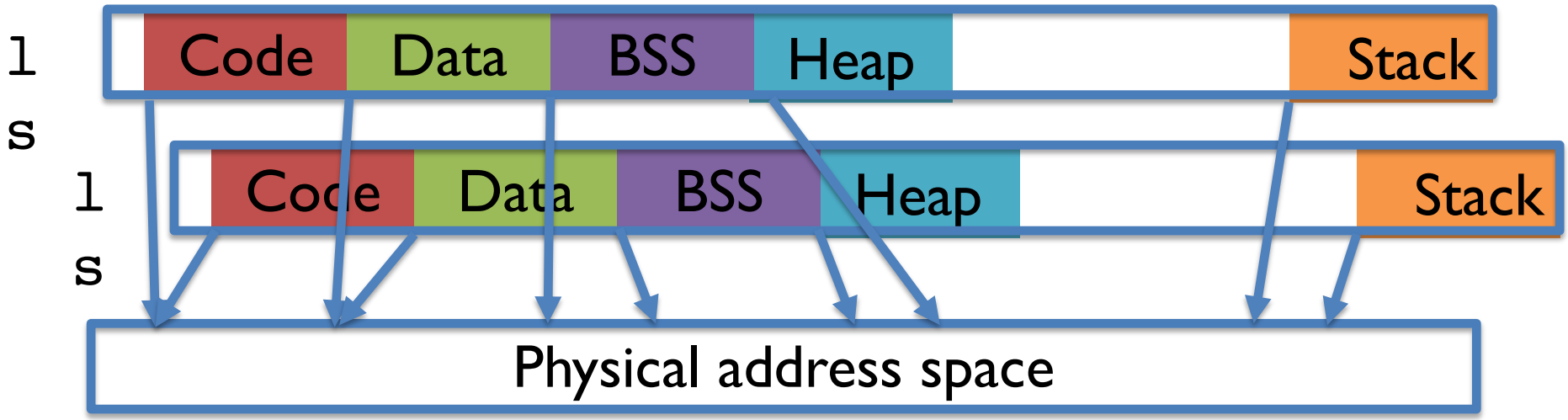
sbreak
system call
now provides
protection.
sbrk()
introduced
1975 V5:
brk() introduced
1983
4.2BSD:
First
references
to mmap()
1970
1980
1990
2000
2010
2020

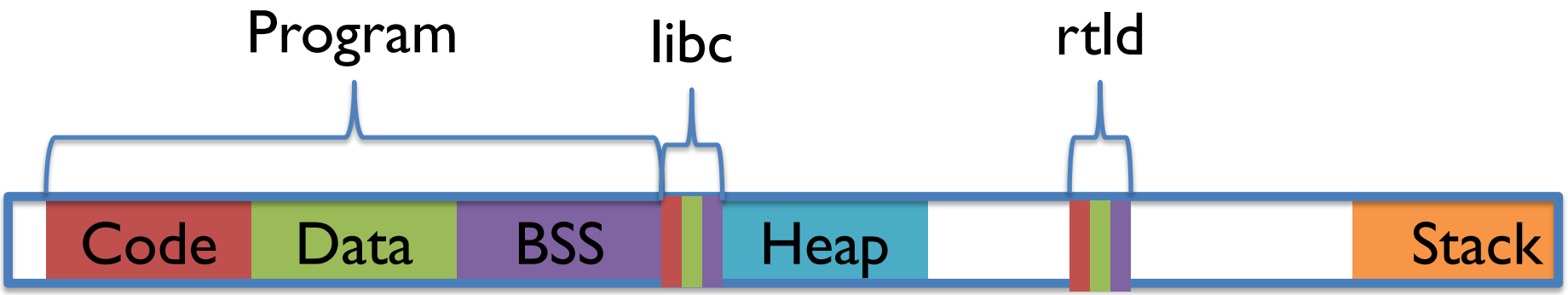
Heap fragmentation



Memory sharing



Dynamic linking



Multi-threaded programs

4.2BSD memory interfaces

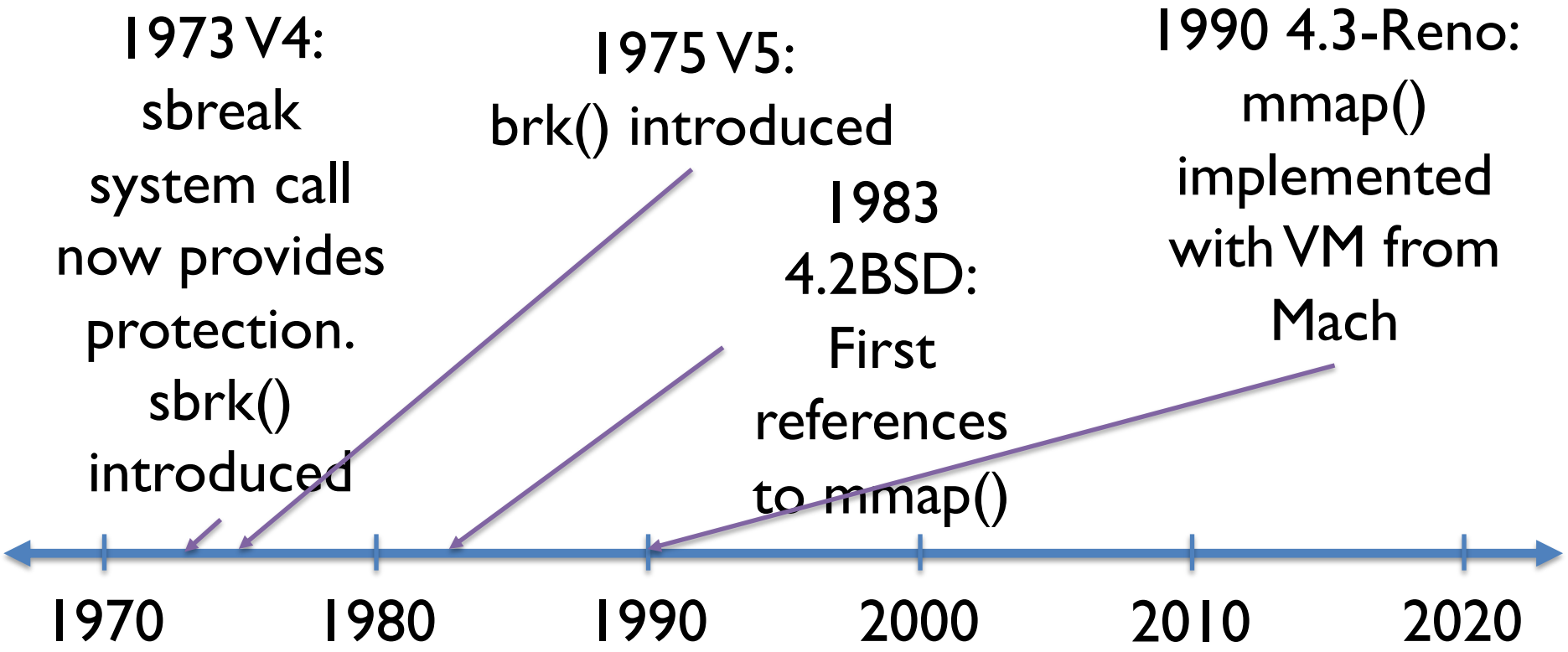
- mmap()
  - Allocate address space
  - Alter backing mappings
- mremap()
  - Relocate or extend mapping
- munmap()
  - Remove backing

4.2BSD memory interfaces

- mprotect()
  - Alter page protections
- madvise()
  - H…
- …
- sbrk()
  - …
  - …xtend or reduce stack
  - …ing status

Only sbrk() implemented!

UNIX and BSD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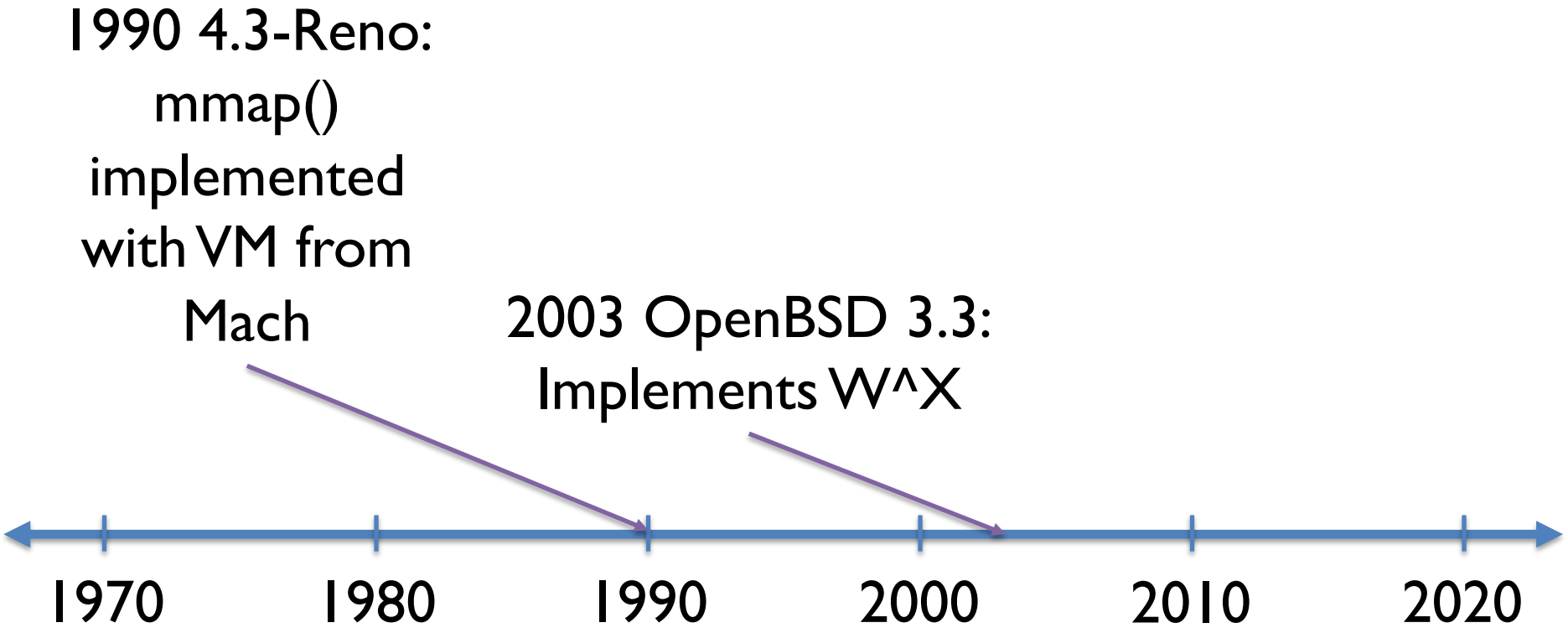
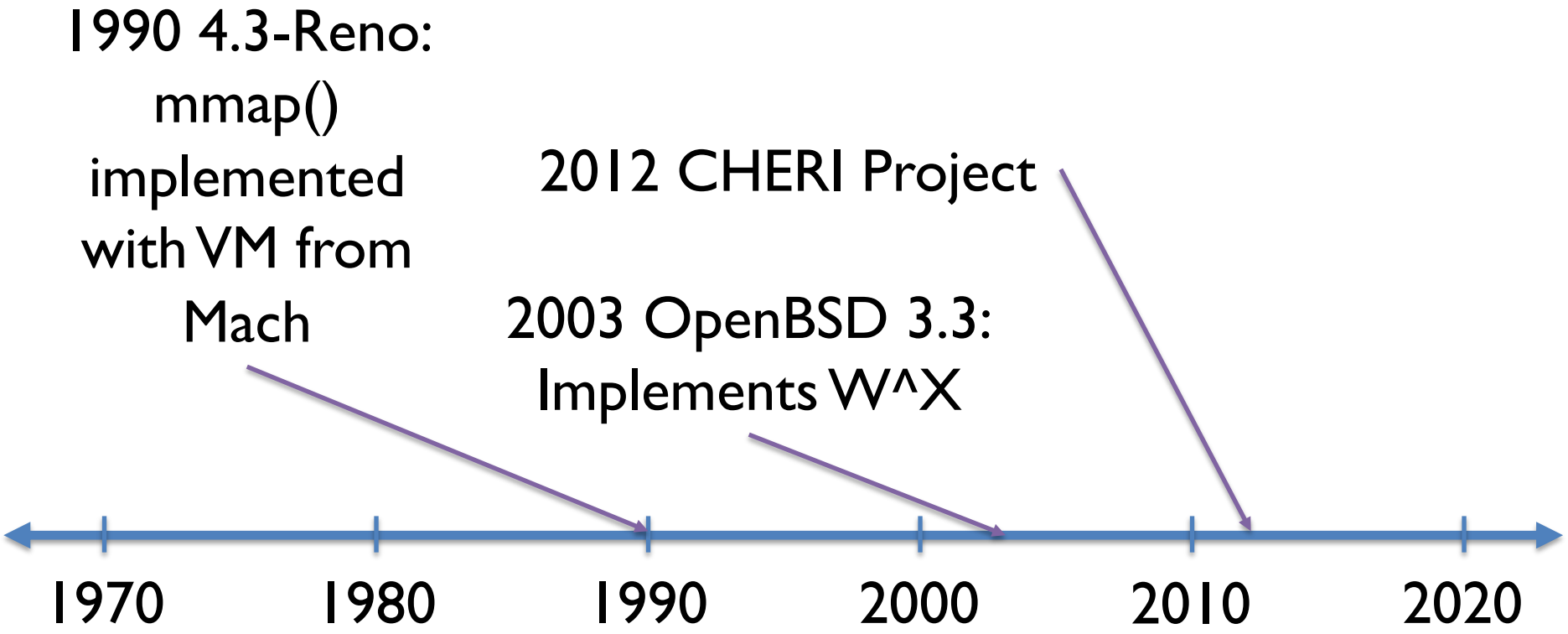
UNIX and BSD



W^X and JITs

- Prohibits pages from having both PROT_EXEC and PROT_WRITE simultaneously
- JITs need to write then execute!
- Solution: Map PROT_WRITE then remove PROT_WRITE and add PROT_EXEC
- New problem: most pages should not become executable, but mmap() cannot express this!

UNIX and BSD


1990 4.3-Reno: mmap() implemented with VM from Mach
2012 CHERI Project
2003 OpenBSD 3.3: Implements W^X
1970
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2020

CHERI pointers

- Pointers with bounds and permissions
  - With strong monotonicity guarantees
- Want W^X for pointers (in addition to pages)
- API changes required:
  - Should mprotect() return a pointer?
  - Should some other mechanism be used?

mmap() functionality issues

- Interface conflates address reservation and mapping
  - Lack of boundaries between reservations leads to bugs: e.g. Stack Clash
- Lack of expressiveness
  - No portable way to express alignment
  - No way to express maximum permission

mmap() API issues

- Too many arguments
  - Can you remember them all?
  - Many calls don't use them all
- Too many failure modes:
  - FreeBSD 11.1: 19 documented errors (15 use EINVAL)

Other mmap() issues

- No support for mapping more pages than requested
  - Can't round up to superpage size
  - CHERI bounds compression requires rounding for very large allocations
- No concept of address space ownership
  - Math errors mean changing the wrong region

RFC: cmmap (1/3)

- int cmreserve(cm_t *handlep, size_t length,
  vaddr_t hint, int prot, cmreq_t *cmr);
  - Reserve a region, optionally mapping.
- int cmgetptr(cm_t handle, void **ptrp);
  - Get a pointer to the region.

RFC: cmmap (2/3)

- int cmmap(cm_t handle, cmreq_t *cmr);
  - Replace (part of) a region's mappings.
- int cmclose(cm_t handle);
  - Close a handle.
- int cmrestrict(cm_t handle, XX ops, XX *oops);
  - Restrict the set of operations on a handle

RFC: cmmap (2/3)

- int cmstat(cm_t handle, size_t index,
  struct cm_stat * cs)
  - Return data on a series of submaps
- cmadvise(), cmincore(), cminherit(), cmsync(), cmunmap()
  - Like mmap() counterparts, but within region

More on map requests

- Request object rather than many arguments
  - cm_request_t following pthread_attr_t model
- Accessor functions to set up request
- Goal: useful defaults
  - Ideally, requests should always be valid

CHERI extensions

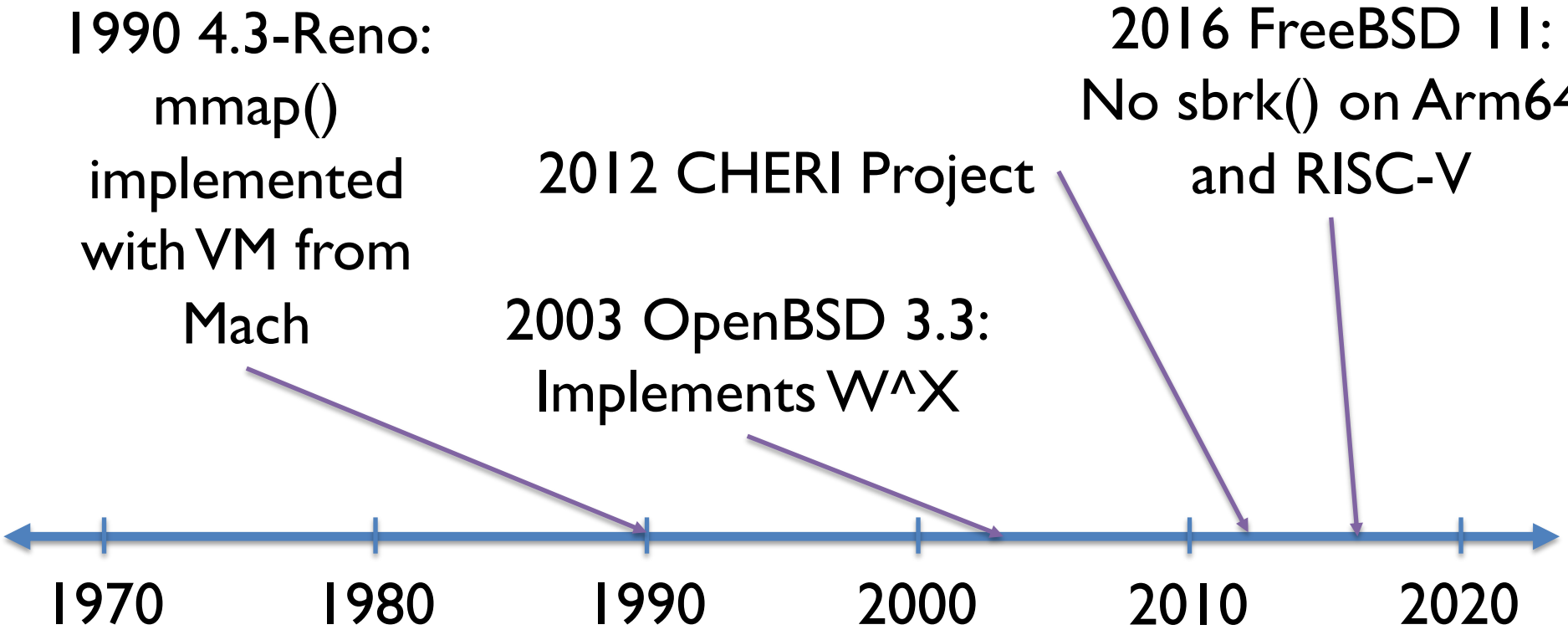
- int cmgetcap(cm_t cookie, void **ptrp,
  perm_t perms)
  - Get a capability pointer
- int cmandperm(cm_t cookie, perm_t perms,
  perm_t *operms)
  - Reduce the set of allowed permissions

Should we replace mmap()?

Yes or No?

BACKGROUND

UNIX and BSD


1990 4.3-Reno: mmap() implemented with VM from Mach
2003 OpenBSD 3.3: Implements W^X
2012 CHERI Project
2016 FreeBSD 11: No sbrk() on Arm64 and RISC-V
1970
1980
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Removing sbrk()

- Mostly incorrect attempts to measure heap use
  - Usually can be disabled, but some force required
- A few internal allocators
  - Usually can be disabled
- Some LISP interpreters
  - Mostly unpopular ones

Removing sbrk() (cont.)