TECHNISCHE UNIVERSITÄT DRESDEN

Faculty of Computer Science Institute of Systems Architecture, Operating Systems Group

MEMORY

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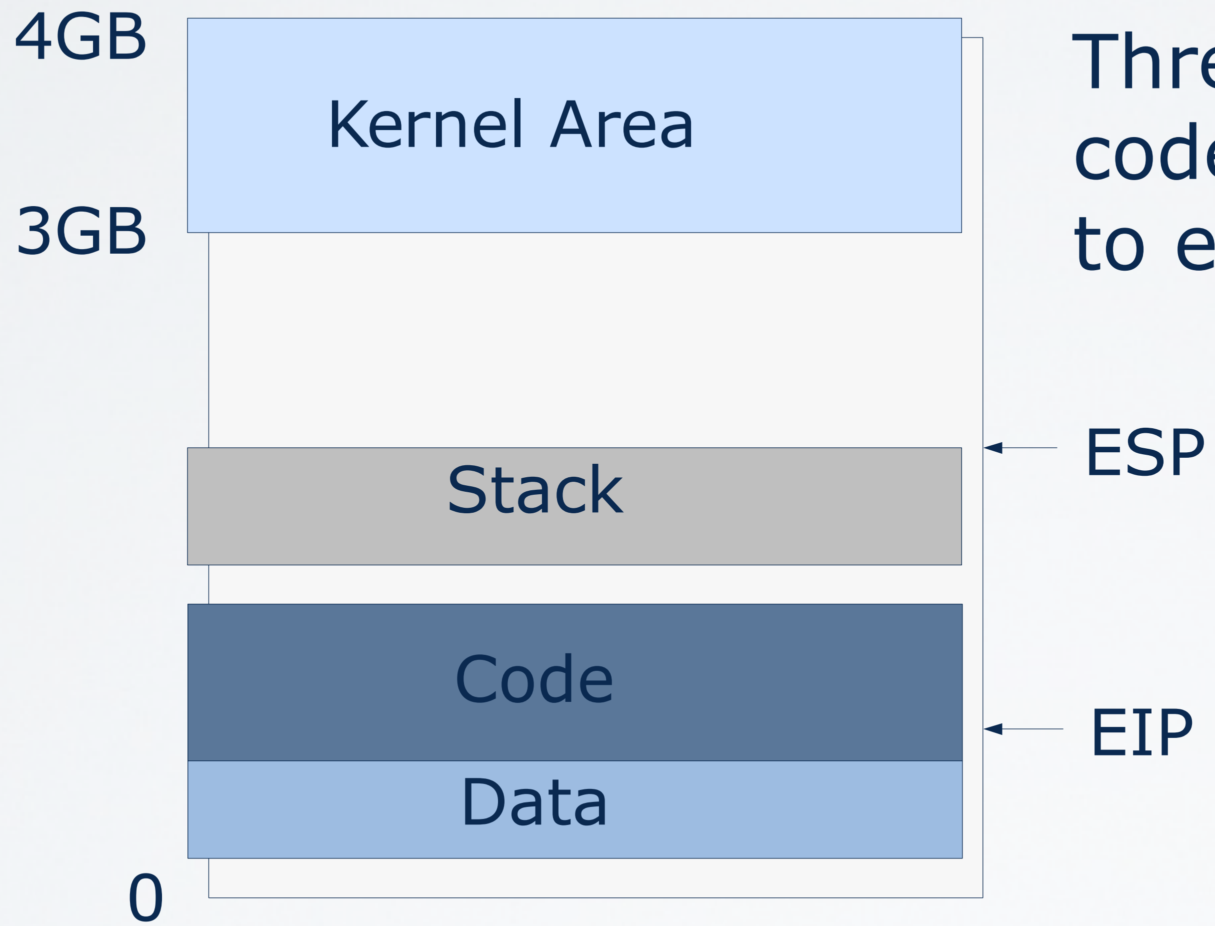
AGENDA

- Introduction
  - Monolithic vs. microkernels
  - L4 concepts: Threads and IPC
  - Fiasco.OC/TUDOS introduction

- **Today: Memory Management**
  - Task creation
  - Page-fault handling
  - Flexpages
  - Hierarchical pagers
  - Region manager
  - Dataspaces

TASK CREATION

ADDRESS SPACE



Thread needs to access code/data/stack/… to execute

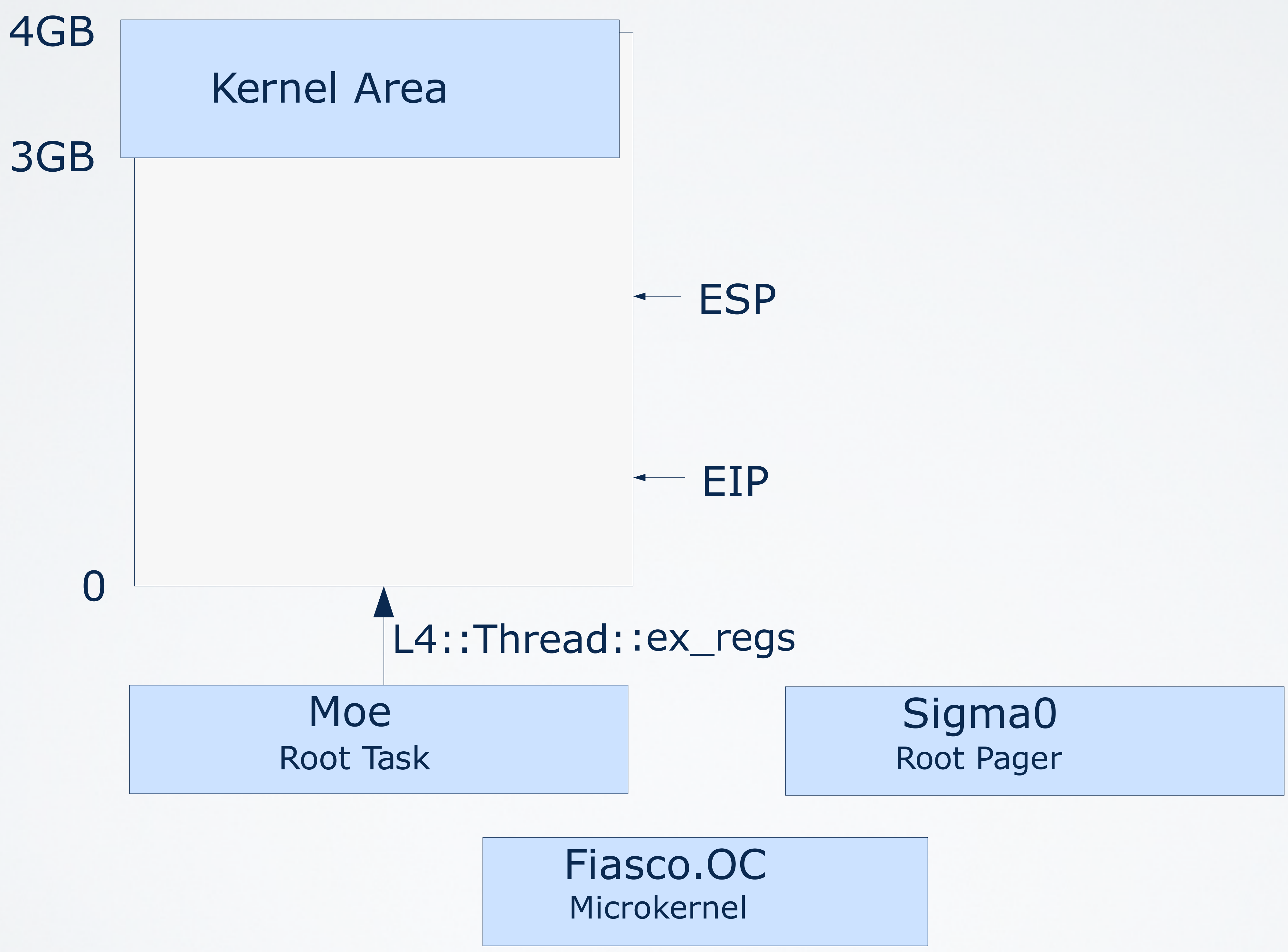
CREATION

```
/* Create a new task. */
l4_msgtag_t
L4::Factory::create_task  (Cap< Task > const &  task_cap,
                           l4_fpage_t const &    utcb_area,
                           l4_utcb_t             *utcb = l4_utcb()
)


/* Create a new thread. */
l4_msgtag_t
L4::Factory::create_thread  (Cap< Thread > const &  target_cap,
                             l4_utcb_t              *utcb = l4_utcb()
)
```

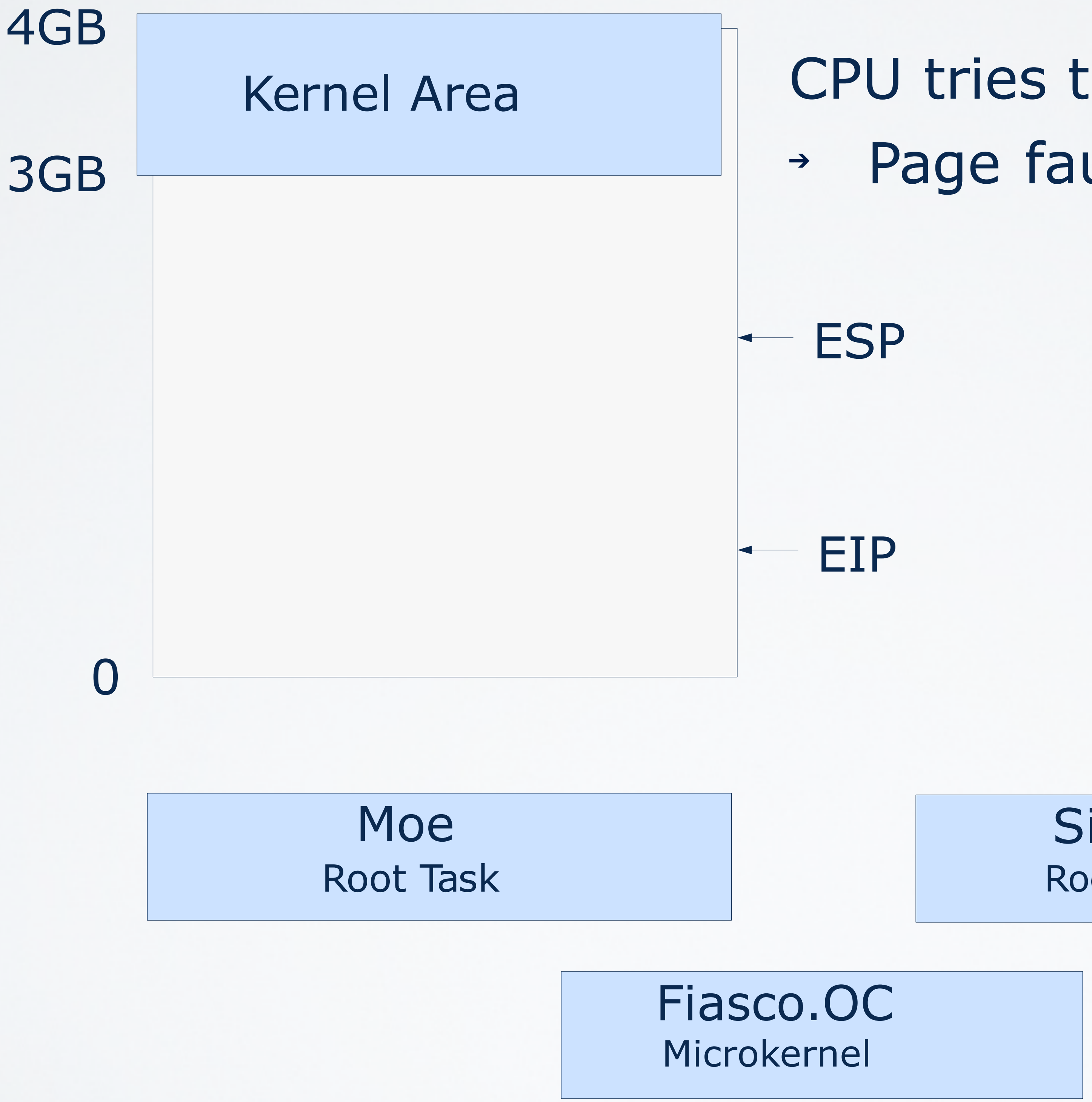
CREATION

```
/* Commit the given thread-attributes object.   */
l4_msgtag_t
L4::Thread::control (Attr const &  attr)


/* Exchange basic thread registers.   */
l4_msgtag_t
L4::Thread::ex_regs  (l4_addr_t       ip,          /* instruction pointer  */
                      l4_addr_t       sp,          /* stack pointer  */
                      l4_umword_t  flags,
                      l4_utcb_t       *utcb = l4_utcb()
)
```

EX_REGS


4GB
Kernel Area
3GB
ESP
EIP
0
L4::Thread::ex_regs
Moe
Root Task
Sigma0
Root Pager
Fiasco.OC
Microkernel

EX_REGS

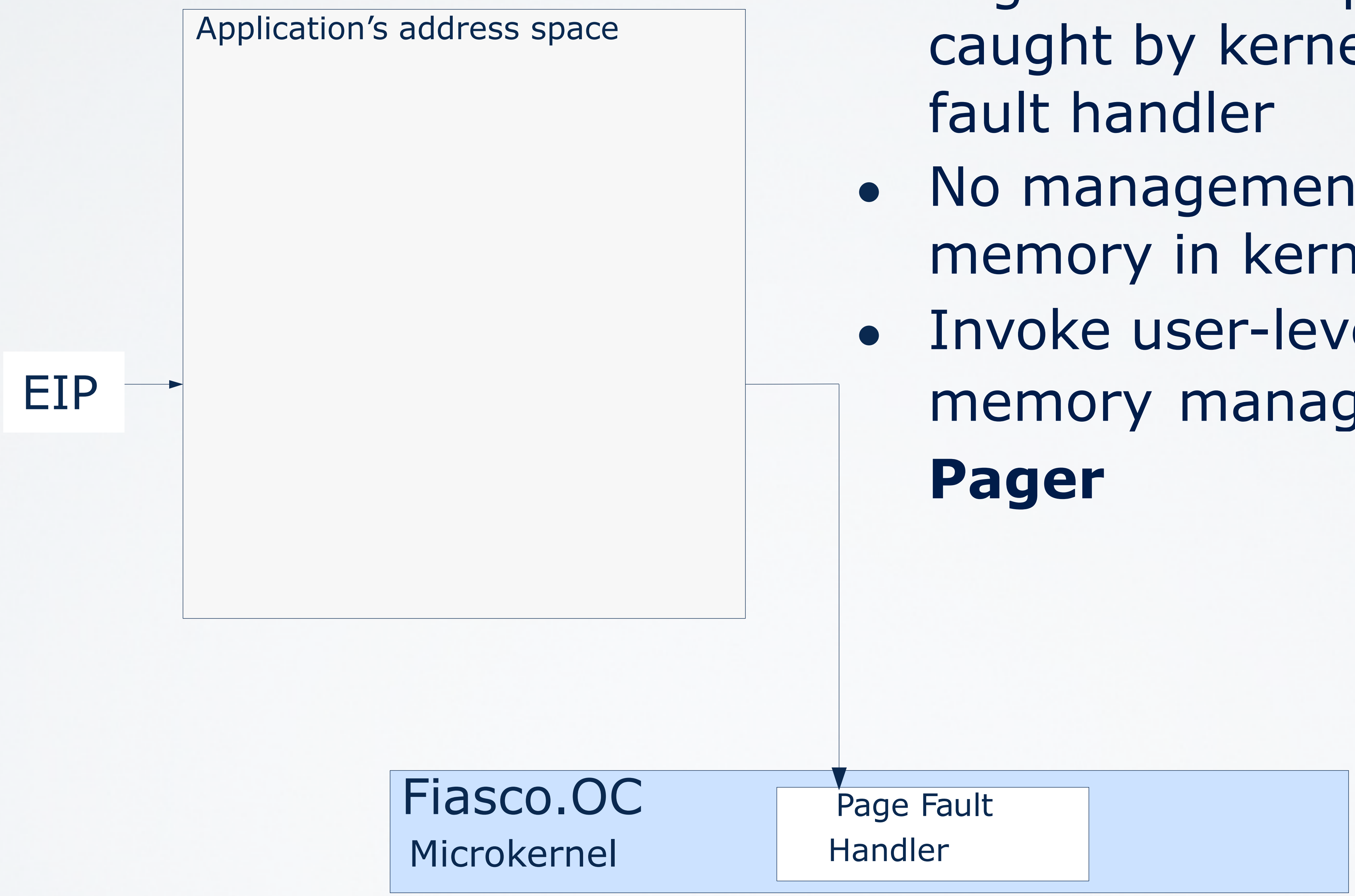


CPU tries to fetch instruction

→ Page fault exception at EIP

PAGE FAULT HANDLING

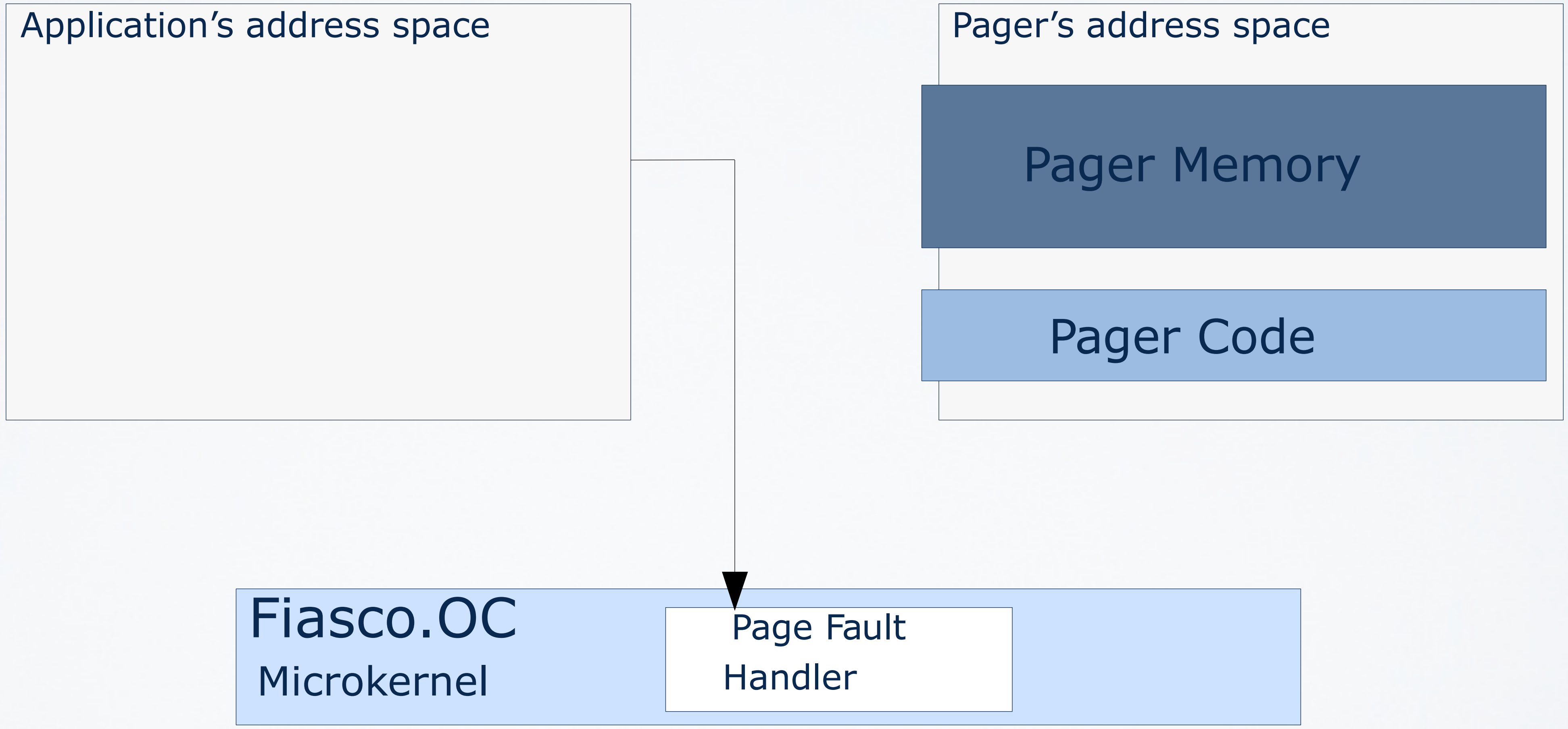
PAGE FAULT



- Page fault exception is caught by kernel page-fault handler
- No management of user memory in kernel
- Invoke user-level memory management → **Pager**

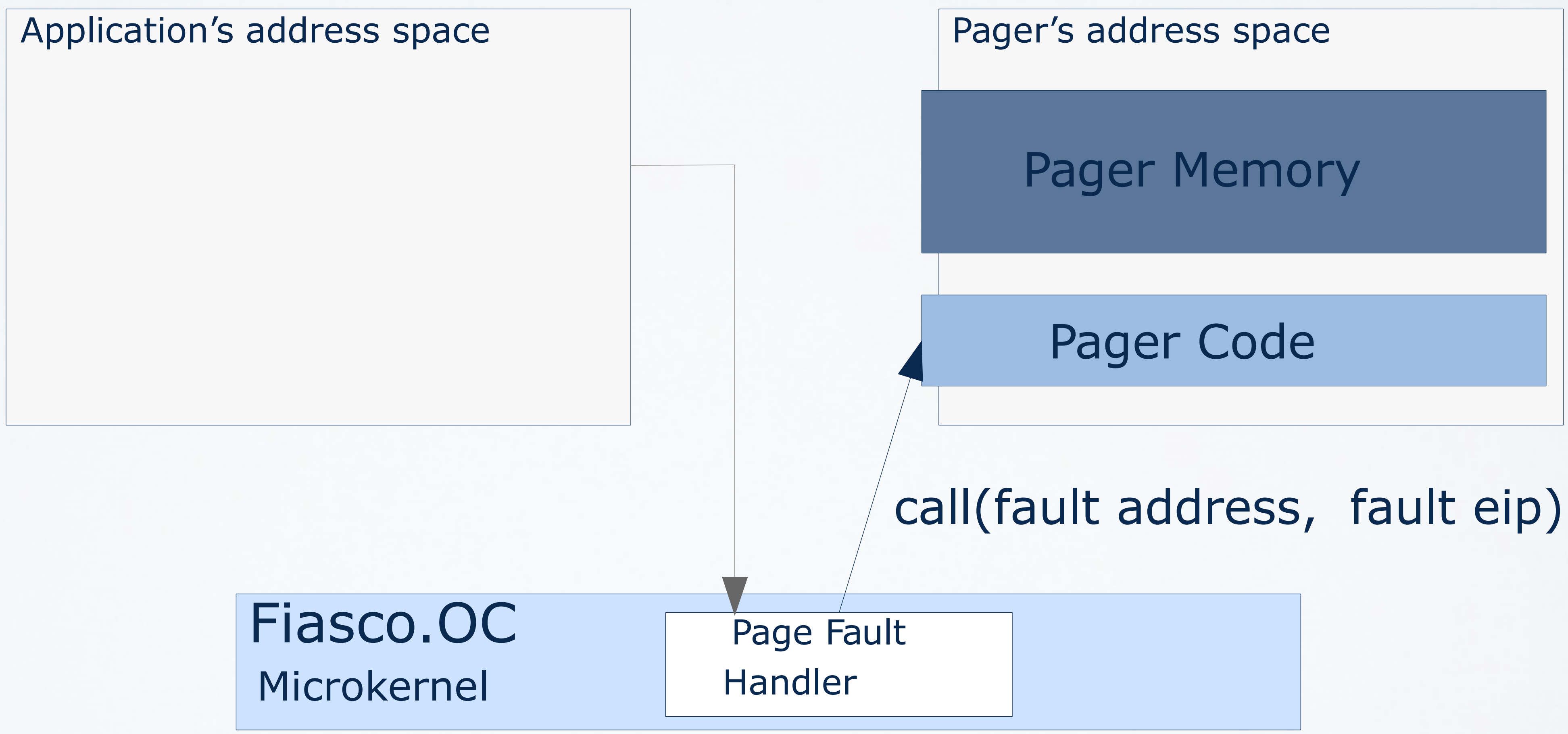
PAGER

- Thread which is invoked on page fault
- Fiasco.OC: each thread has a (potentially different) pager assigned



PAGER INVOCATION

- Communication with pager thread using IPC
- Kernel page fault handler sets up IPC to pager
- Pager sees faulting thread as sender of IPC



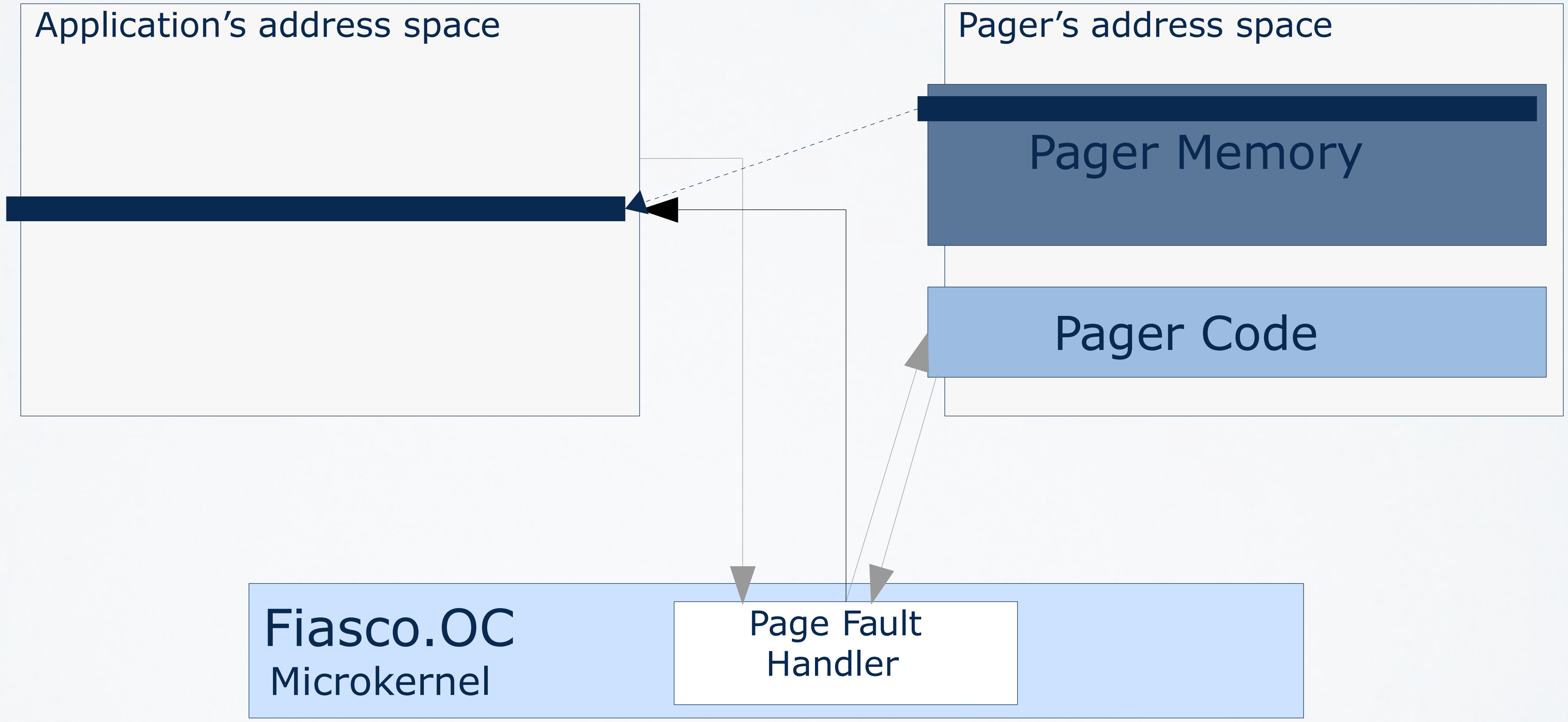
PAGE-FAULT IPC

UTCB[0]	fault address / 4 (30)	*w*	*p*
UTCB[1]	faulting EIP (32)		

$w = 0$	read page fault
$w = 1$	write page fault
$p = 0$	no page present
$p = 1$	page present

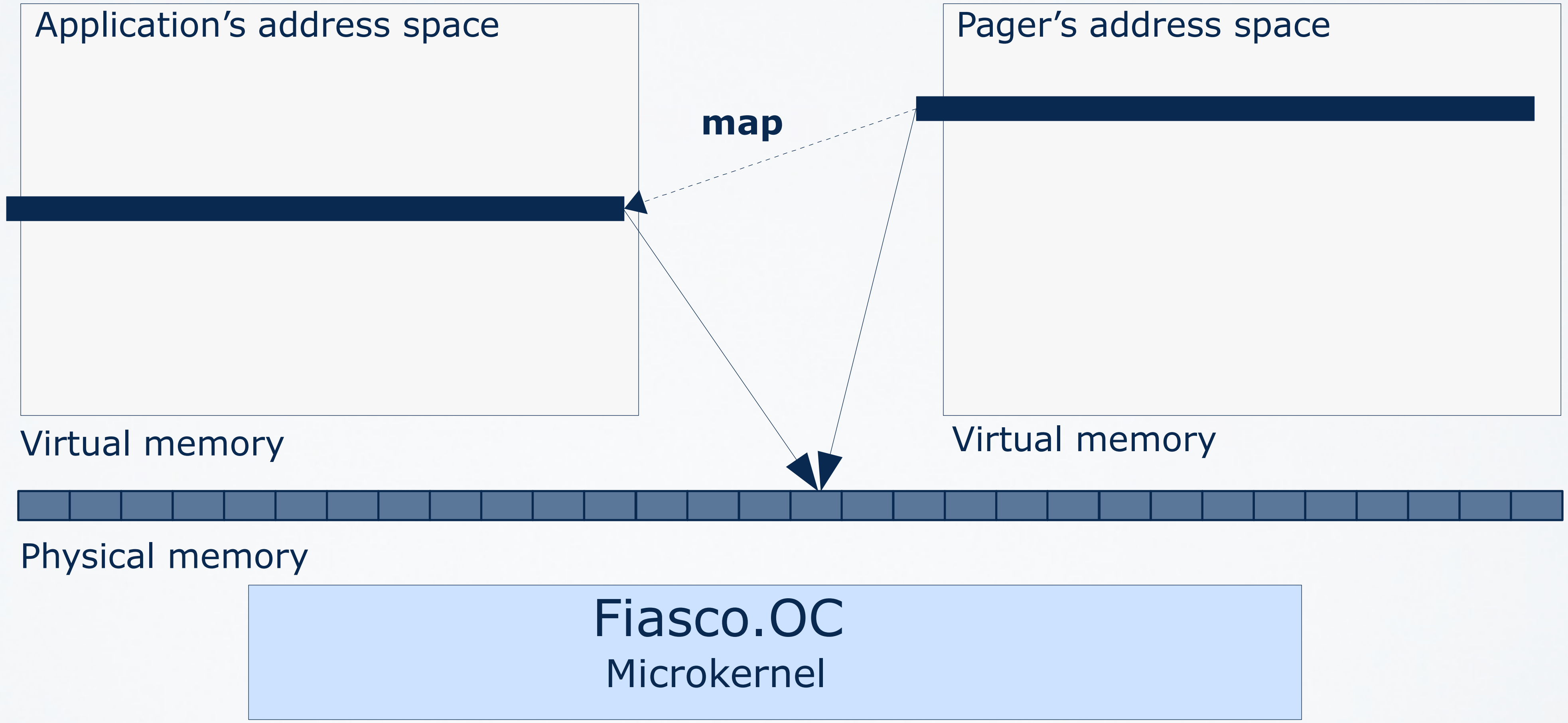
PAGER REPLY

- Pager maps pages of it's own address space to the application's address space
- Flexpage IPC enables these mappings



PAGE MAPPING

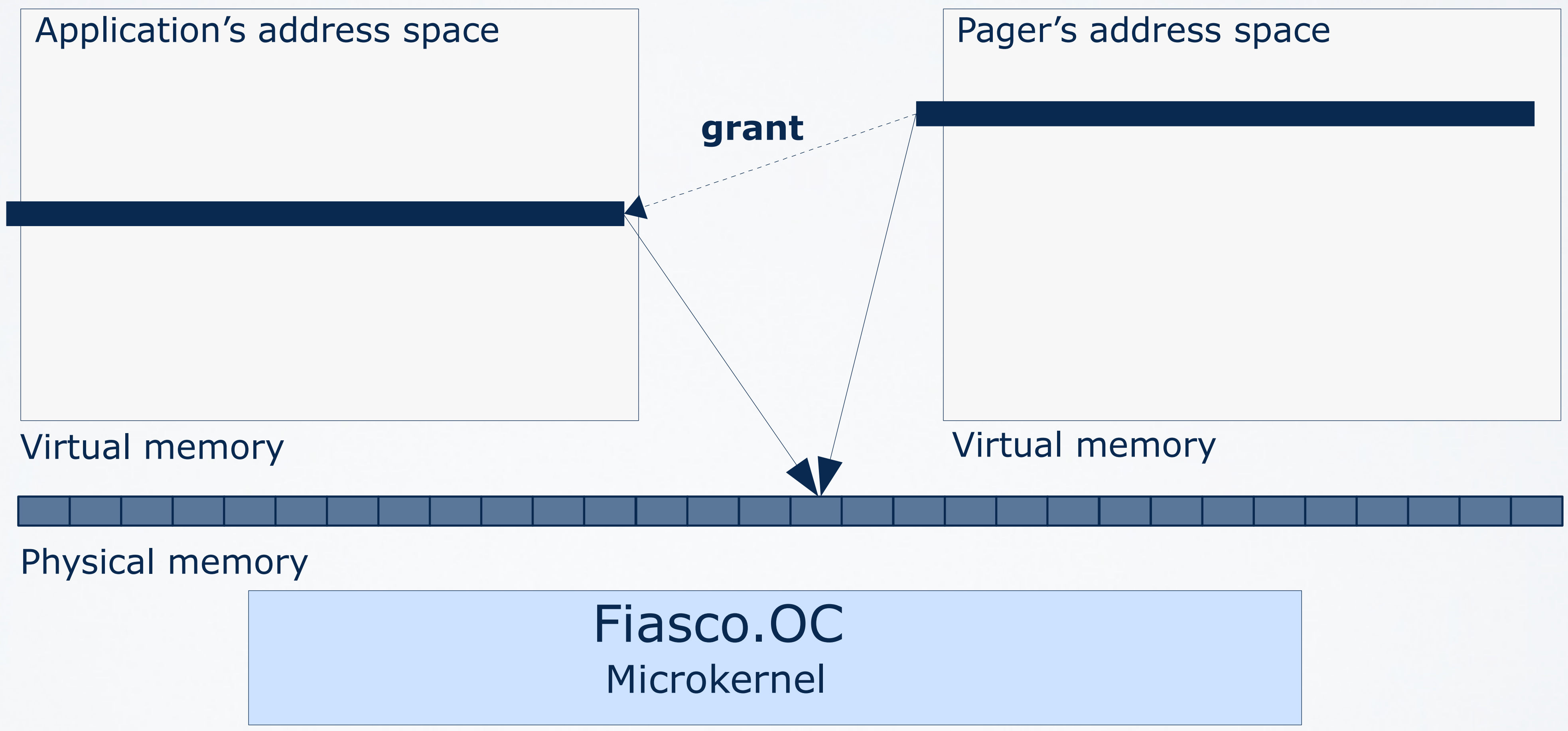
- map() creates an entry in the receiver's address space pointing to the same page frame
  - In hardware: page table entry
- Only valid pager address space entries can be mapped



PAGE GRANTING

- Special case: grant pages (flag: L4_FPAGE_GRANT)

→ Removes mapping from sender's address space

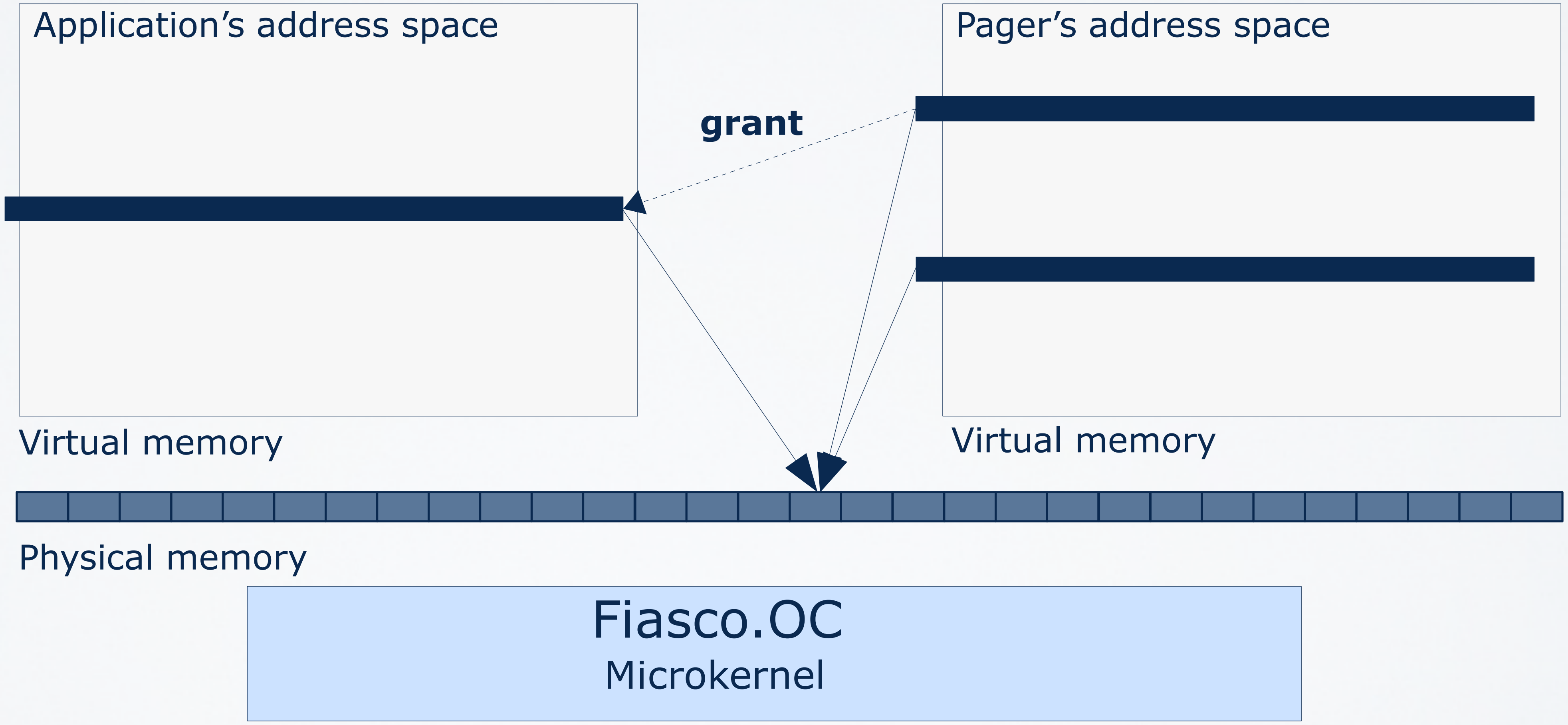


PAGE GRANTING

- Special case: grant pages (flag: L4_FPAGE_GRANT)

→ Removes mapping from sender's address space

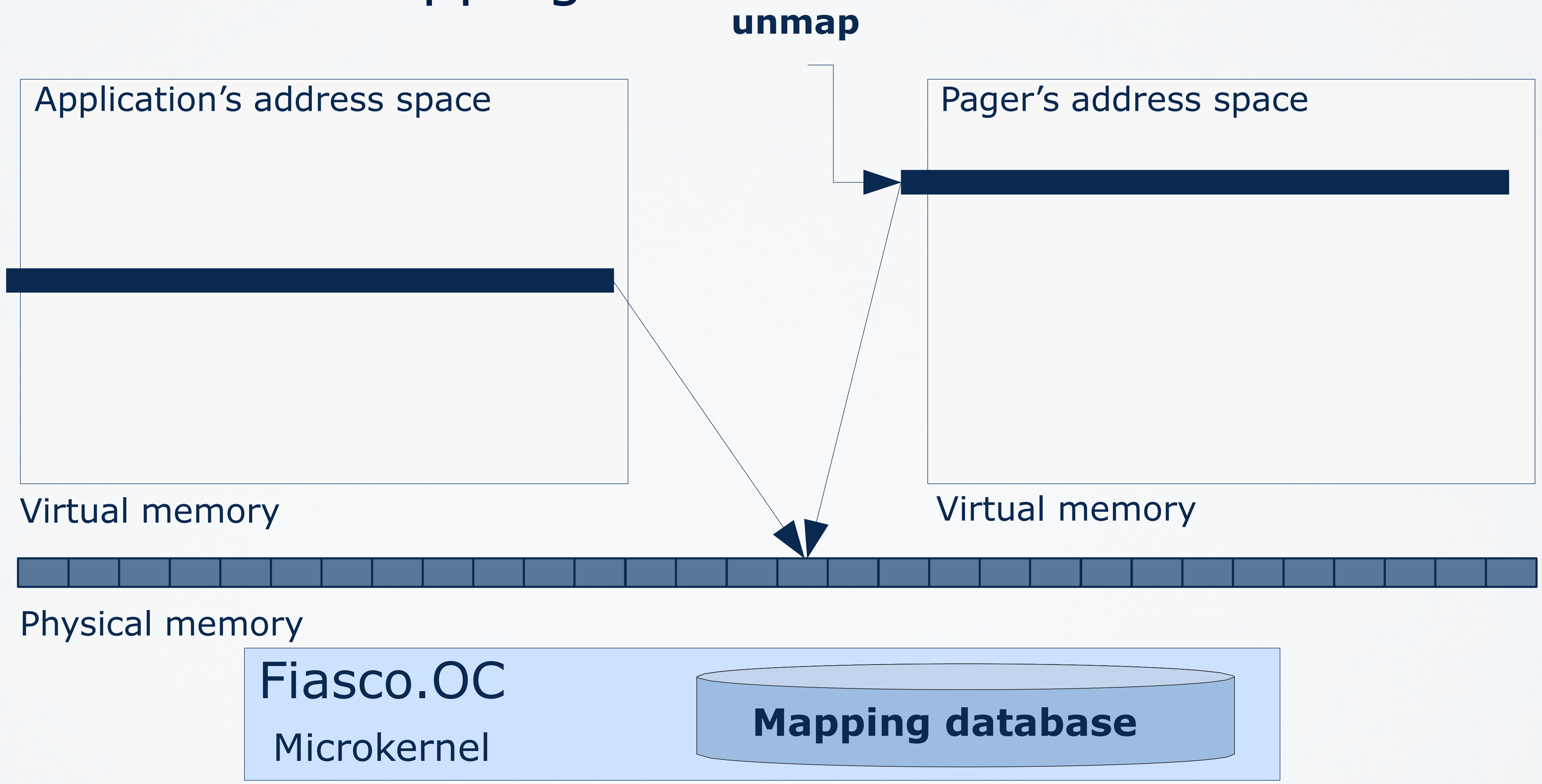
  → ATTENTION: aliases remain



PAGE UN-MAPPING

- Removes entries to a page frame (fpage is specified in invoker's address space)
- Dedicated system call: do not need partner's consent

→ Kernel tracks mappings in a database



FLEXPAGES

FLEXPAGE TYPES

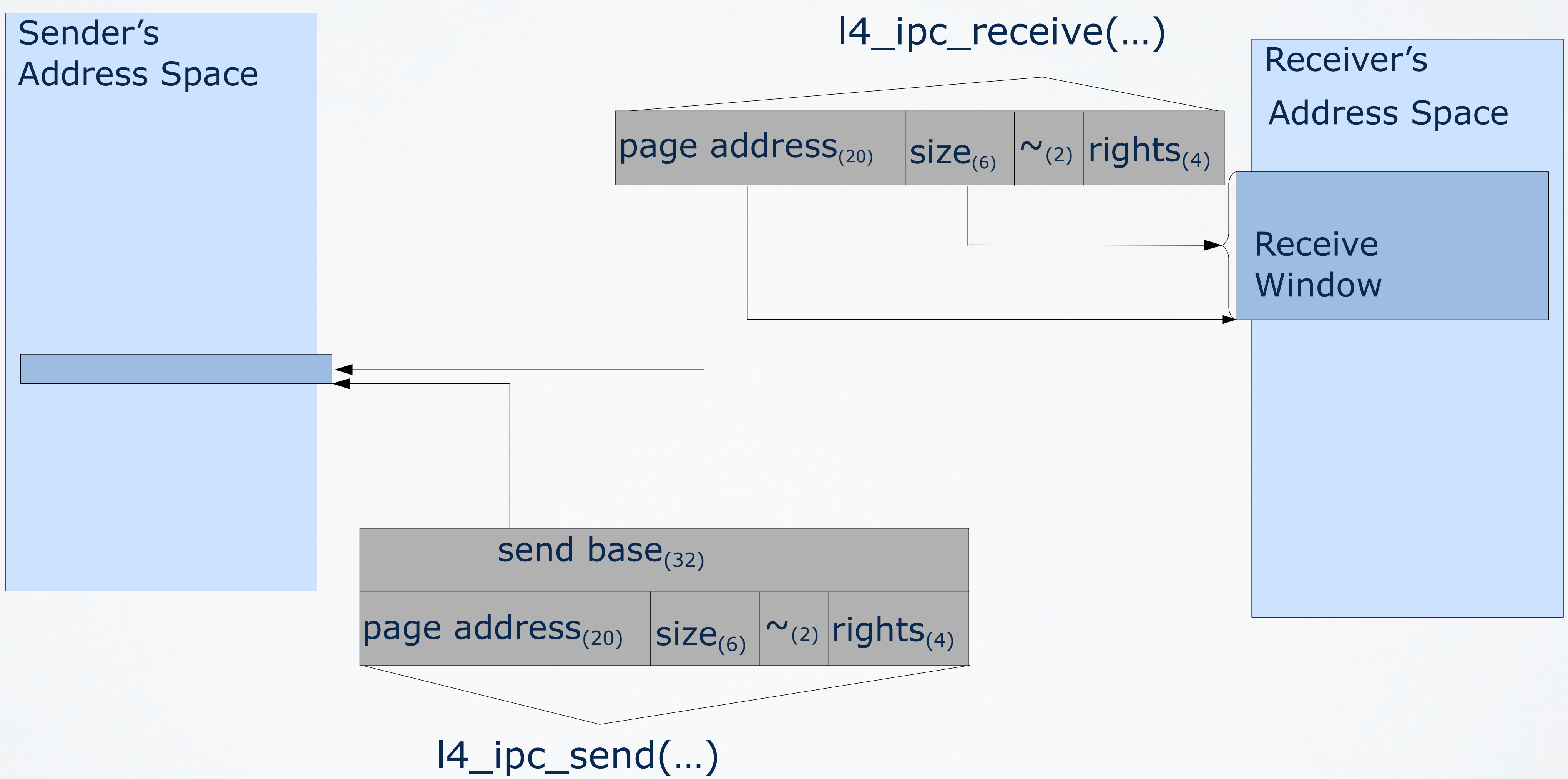
- Flexpages represent resources attached to an address space

- Flexpages in Fiasco.OC are used to describe:
    - Memory pages
    - I/O ports
    - Capabilities

- Today: only flexpages for memory

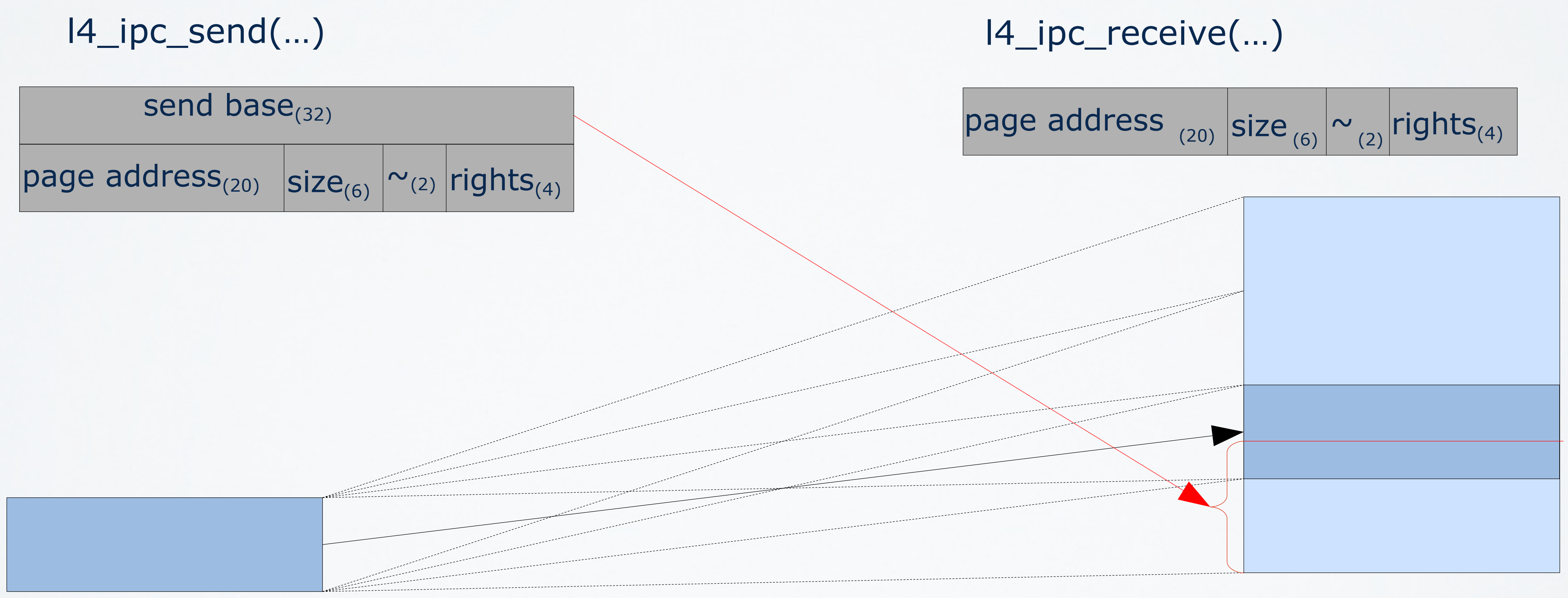
FLEXPAGE IPC

- Size-aligned
- Sizes are **powers of two** → 2^{size}, smallest is hardware page
- Source and target area of a map IPC are described by flexpages



FLEXPAGE OFFSET

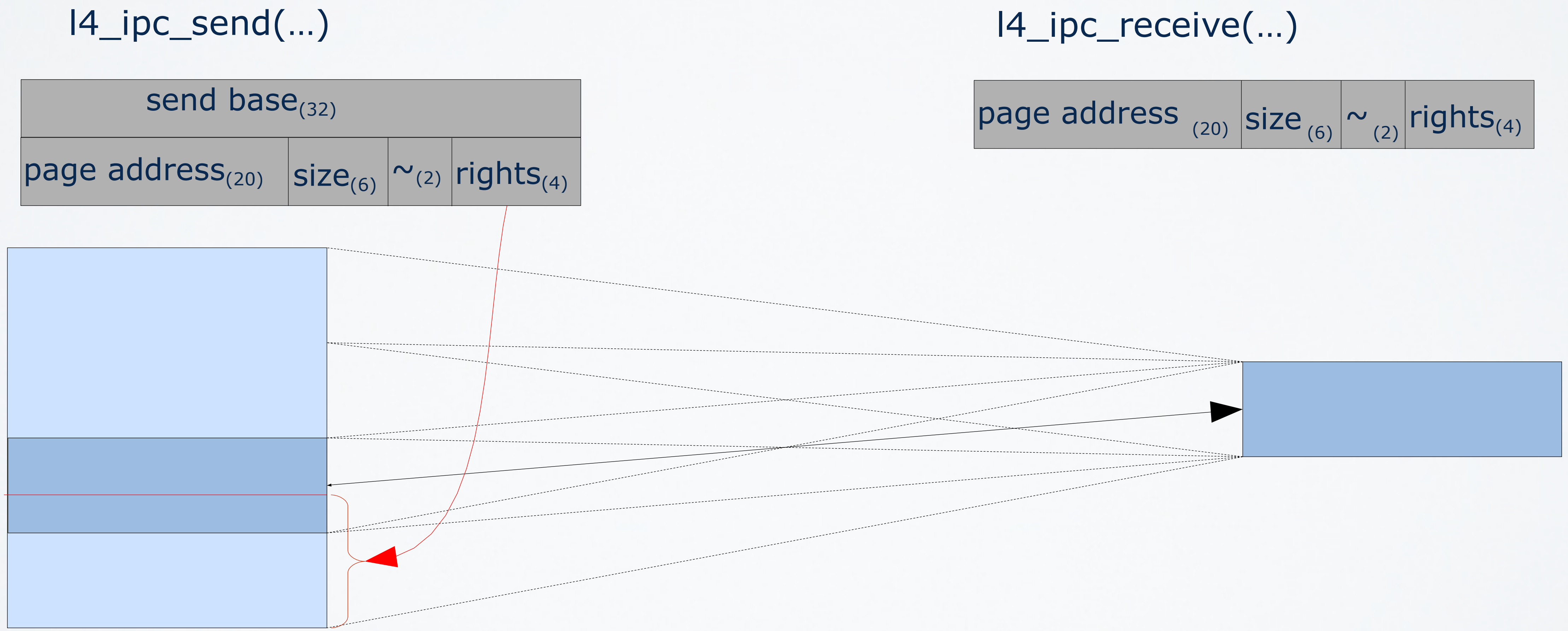
- Send flexpage is smaller than the receive window
  - Target position is derived from send flexpage alignment and send base



FLEXPAGE OFFSET

- Send flexpage is larger than receive window
  - Target position is derived from receive flexpage alignment and send base

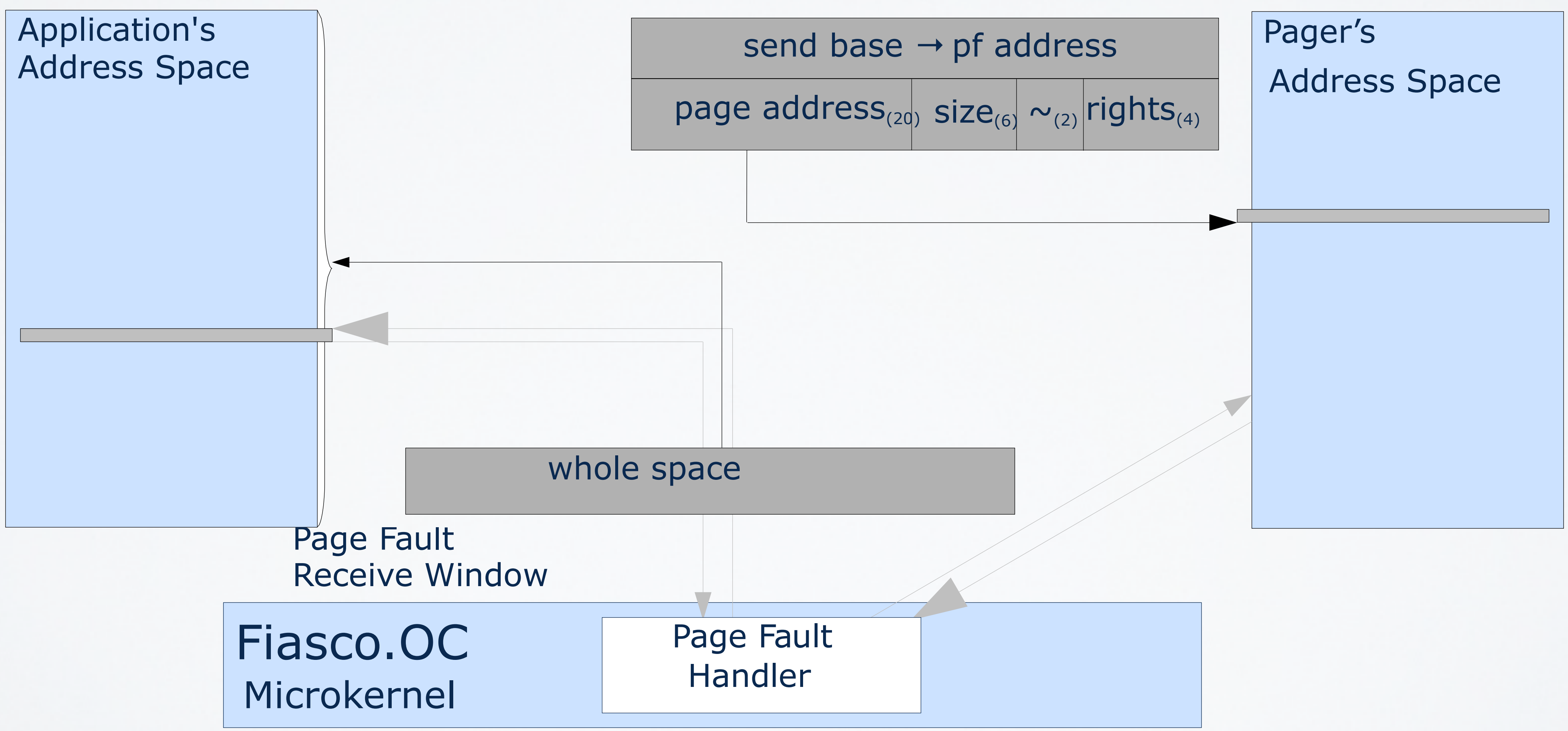
→ Send base depends on information about the receiver



PAGE FAULT

- Kernel page fault handler sets receive window to whole address space

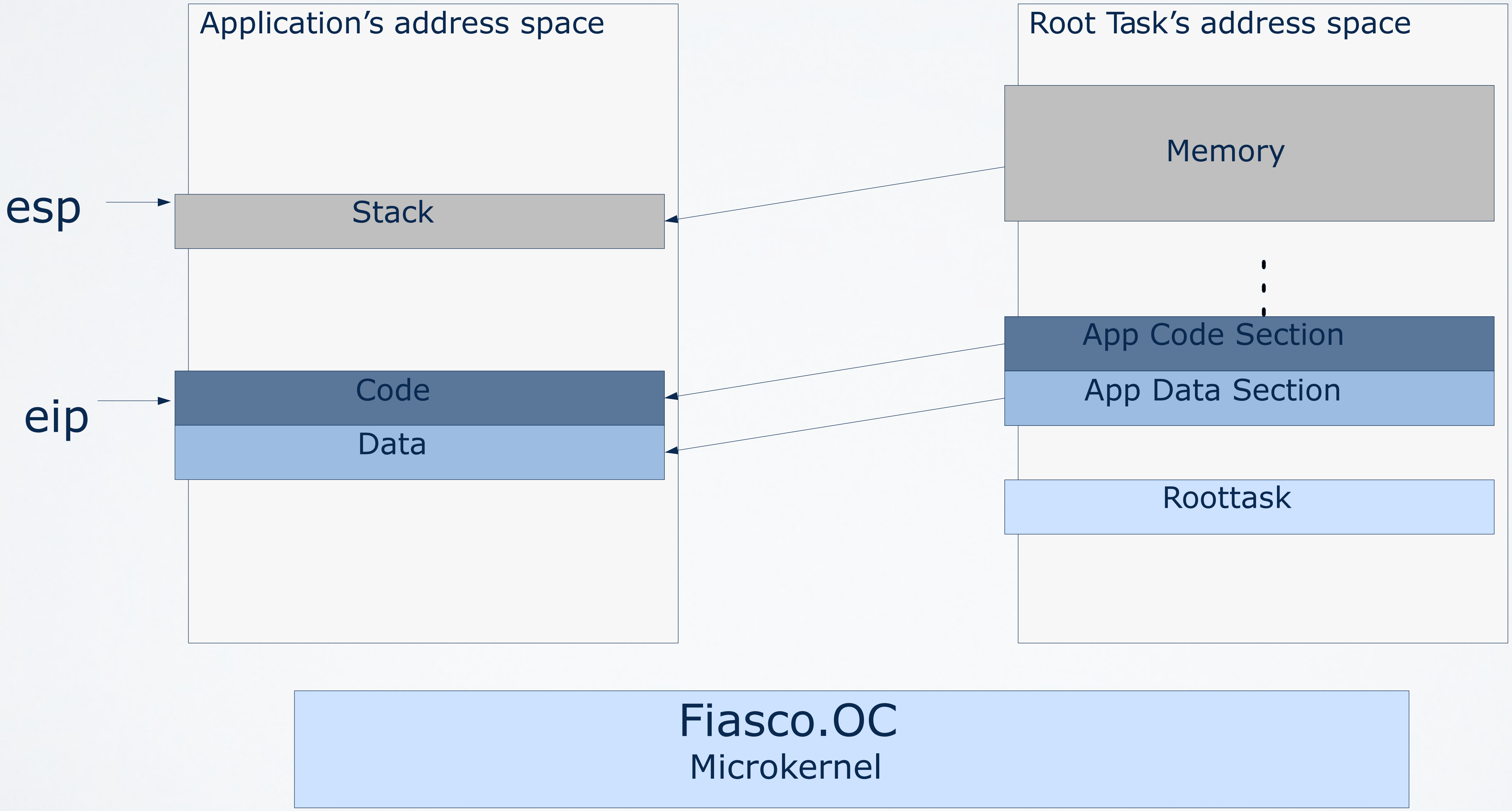
→ Pager can map more than just one page, where the page fault happened to the client



ROOT TASK

- Pages are mapped as they are needed

→ *demand paging*



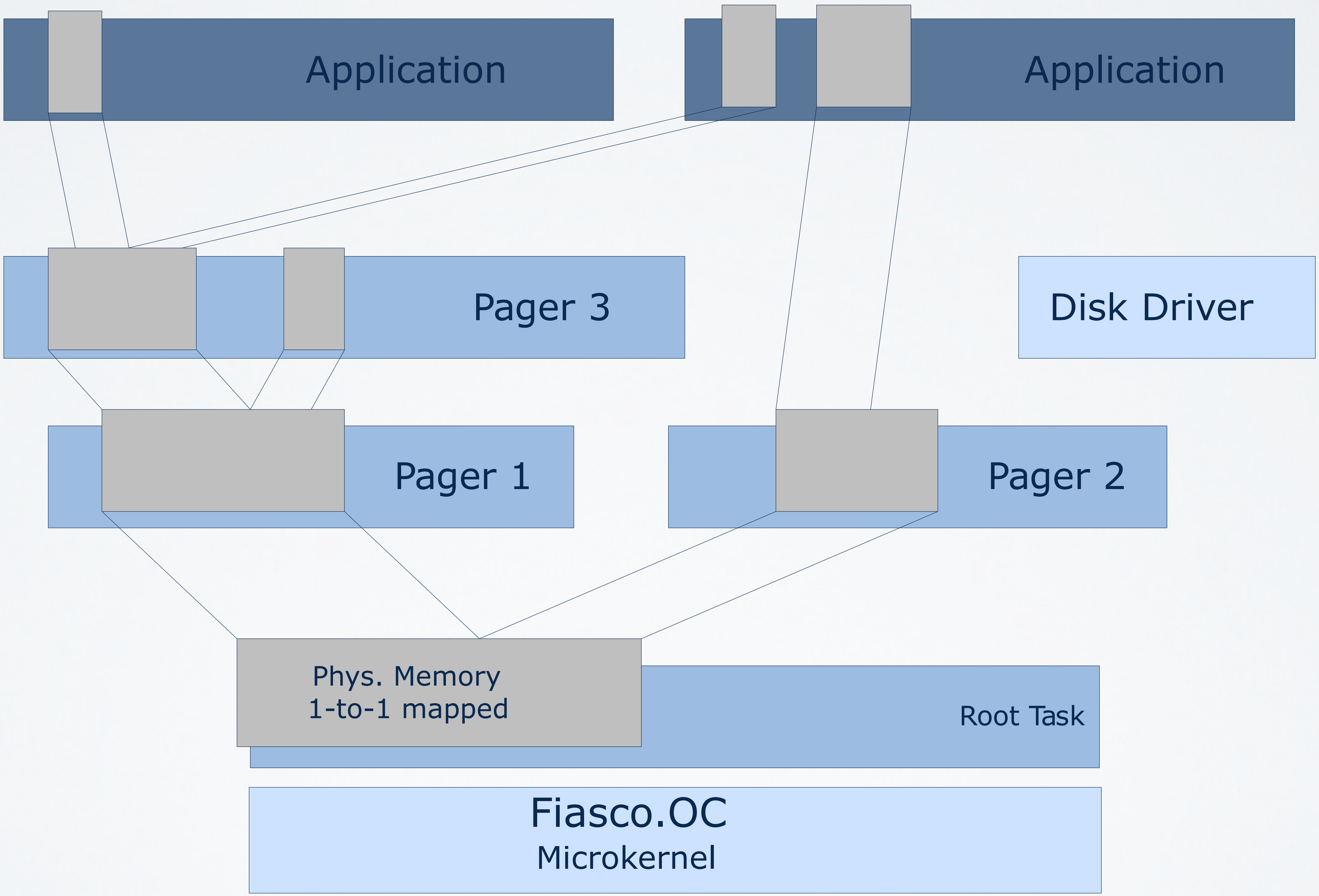
MANAGEMENT

- Initial pager can only implement basic memory management
- No knowledge about application requirements
  - Different requirements at the same time
- Missing services for advanced memory management
  - e.g. no disk driver for swapping
- Build more advanced pagers on top of the initial one

→ Pager hierarchy

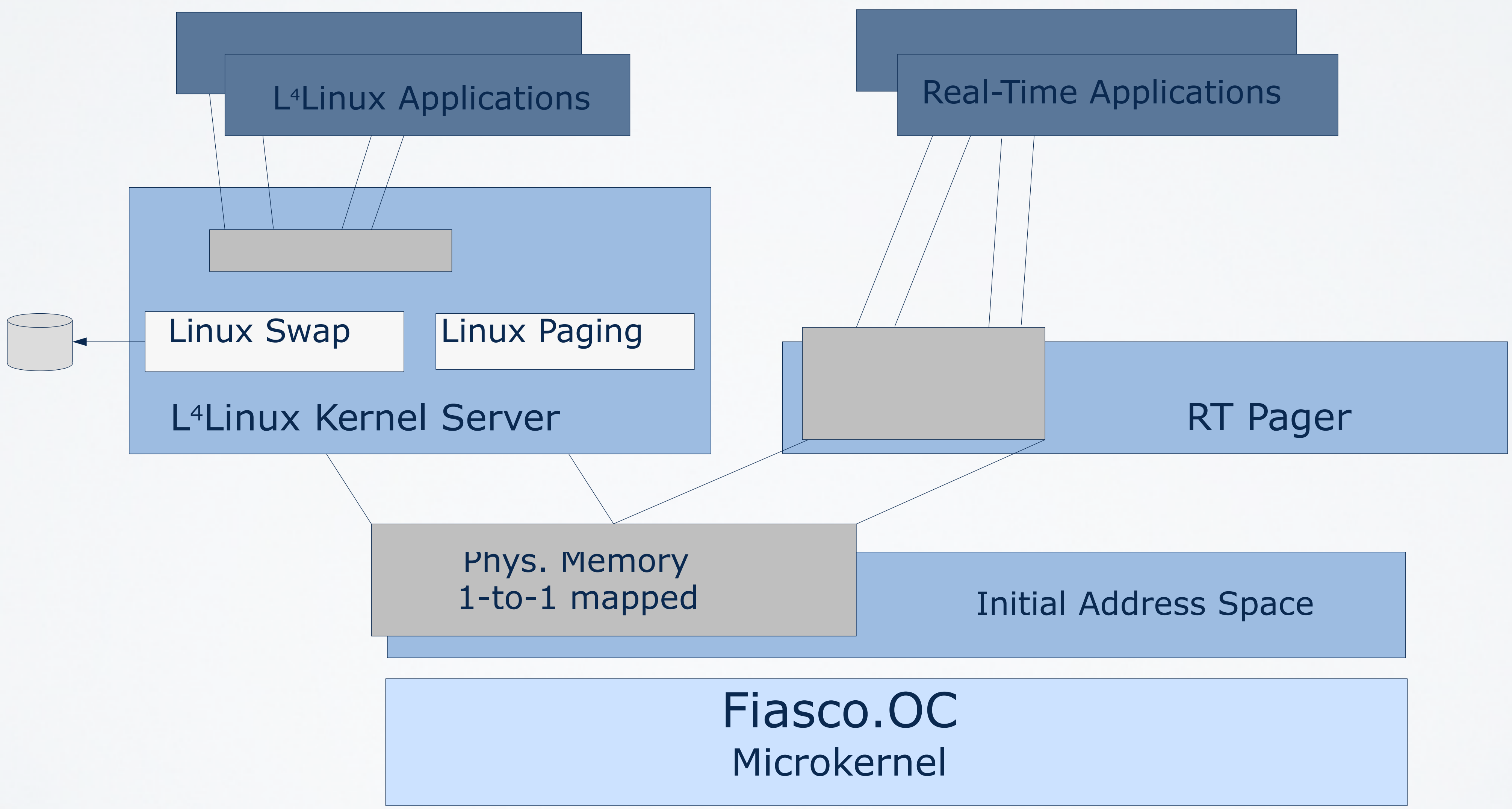
HIERARCHICAL PAGERS

PAGER HIERARCHY



EXAMPLE

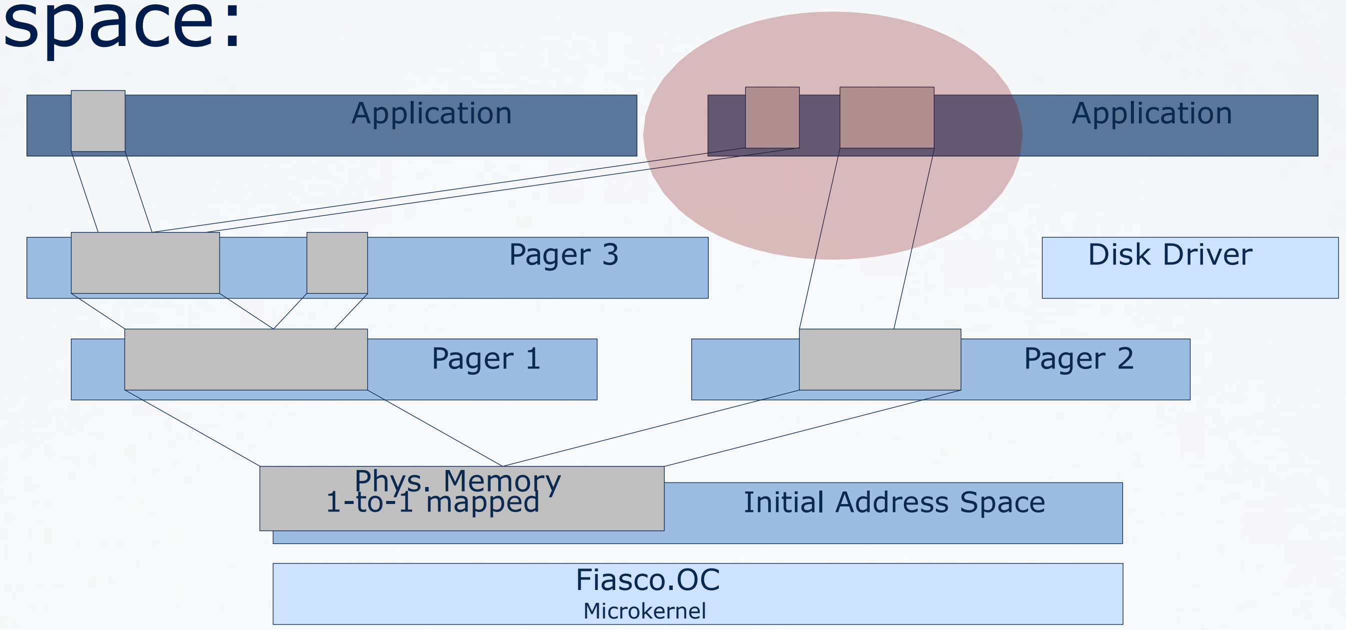
- L^4Linux implements Linux paging policy
- RT pager implements real-time paging policy (e.g. no swapping)



REGION MANAGER

VIRTUAL MEMORY

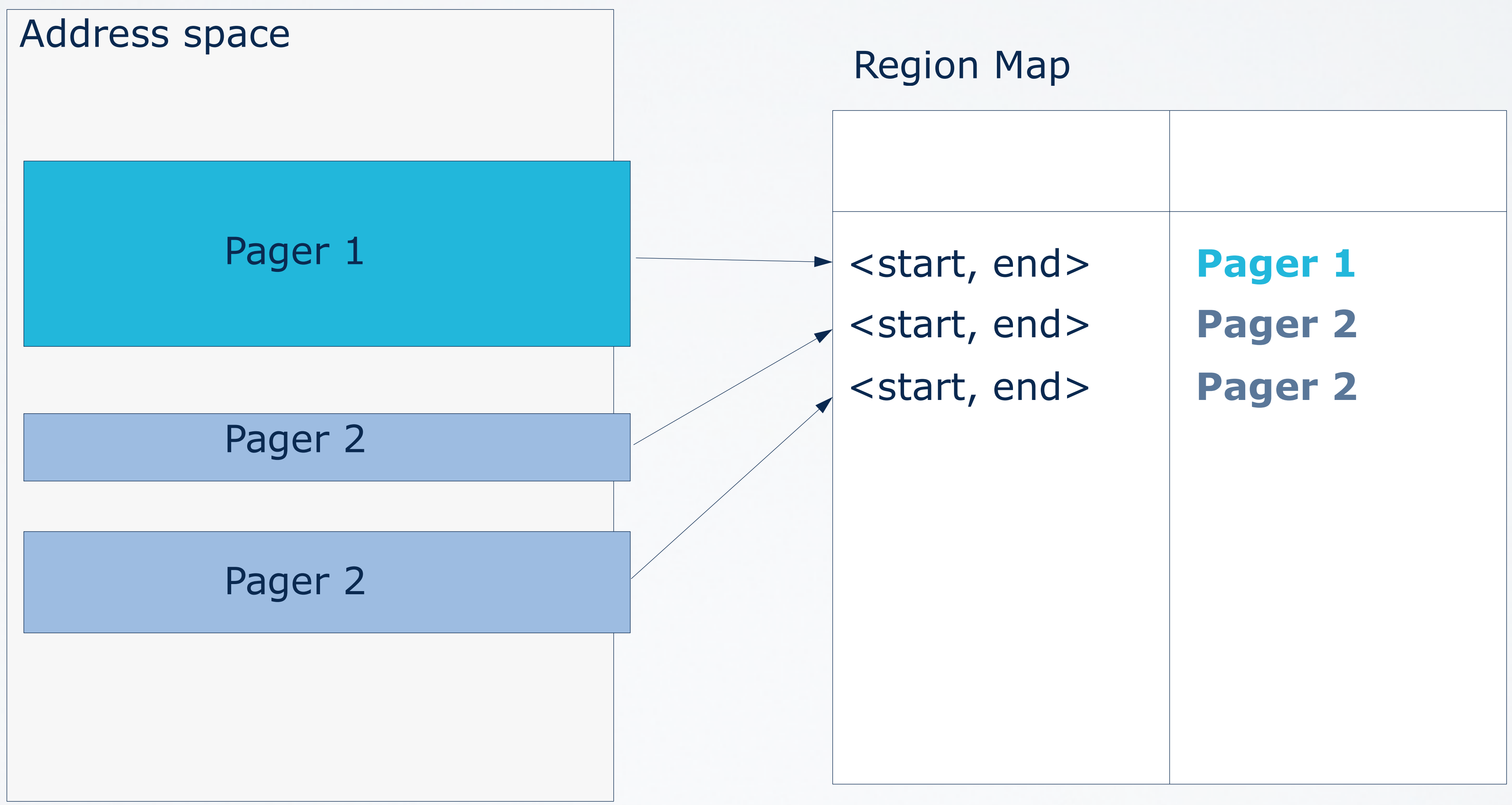
- Pager has to specify send base
- Pager needs to know client's address space layout
  - No problems with only one pager (e.g. L4Linux)
- Possible conflicts if more than one pager manages an address space:



→ Virtual memory must be managed independent of pagers

REGION MAP

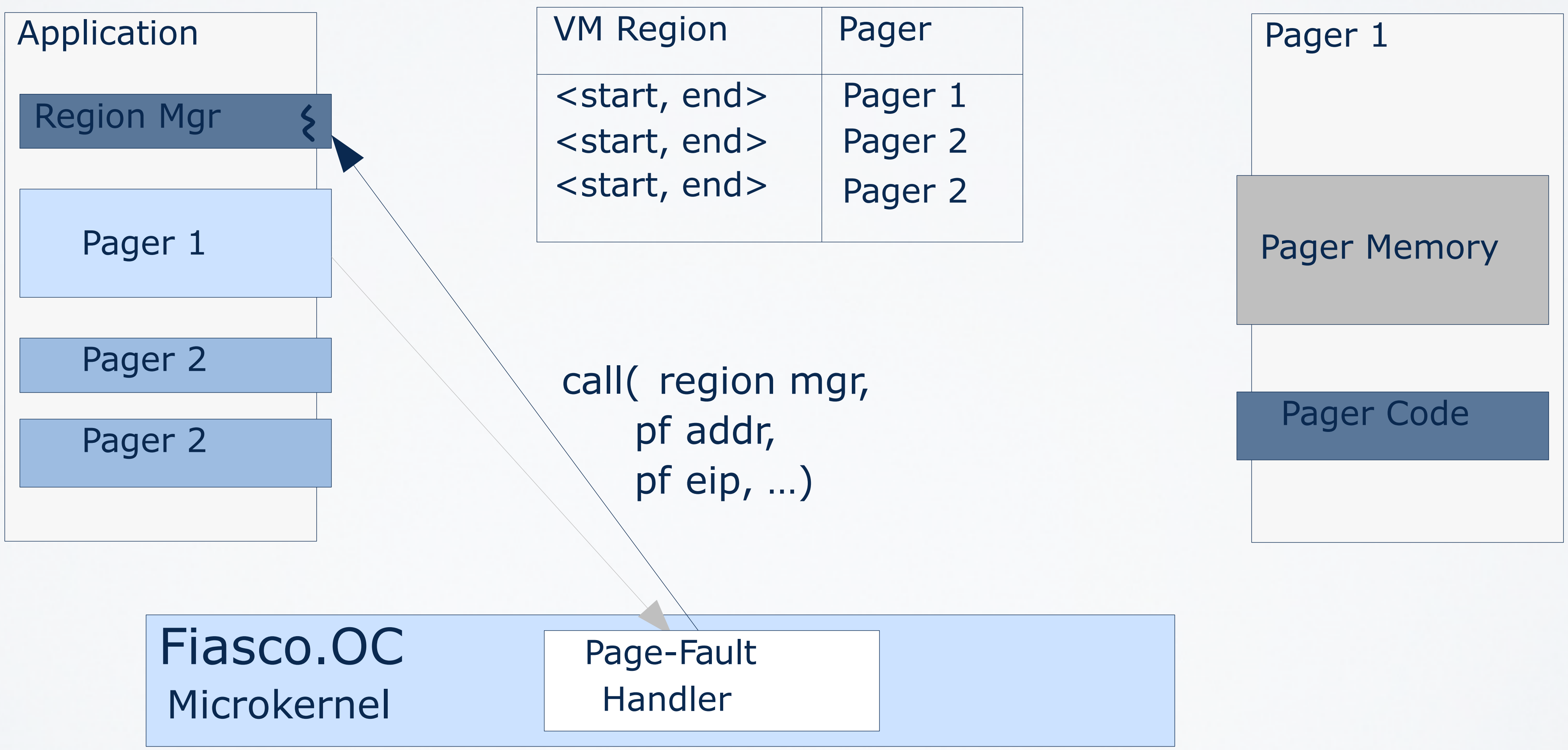
- Per address space map that keeps track which part of the address space is managed by which pager



REGION MANAGER

- Intermediate pager that identifies which pager should handle a page fault
- Resides in the application's address space

→ Region manager is the pager of all threads of a task



REGION MANAGER

- Region manager calls the pager that is responsible
- Receive window gets restricted to the area managed by that pager

→ No interference between different pagers

ABSTRACTION

- Memory management in terms of pages so far
- Application’s view to memory:
  - code / data sections
  - memory mapped files
  - anonymous memory (heaps, stacks, …)
  - network / file system buffers
  - …

→ Abstraction to map this view to low-level memory management

DATASPACES

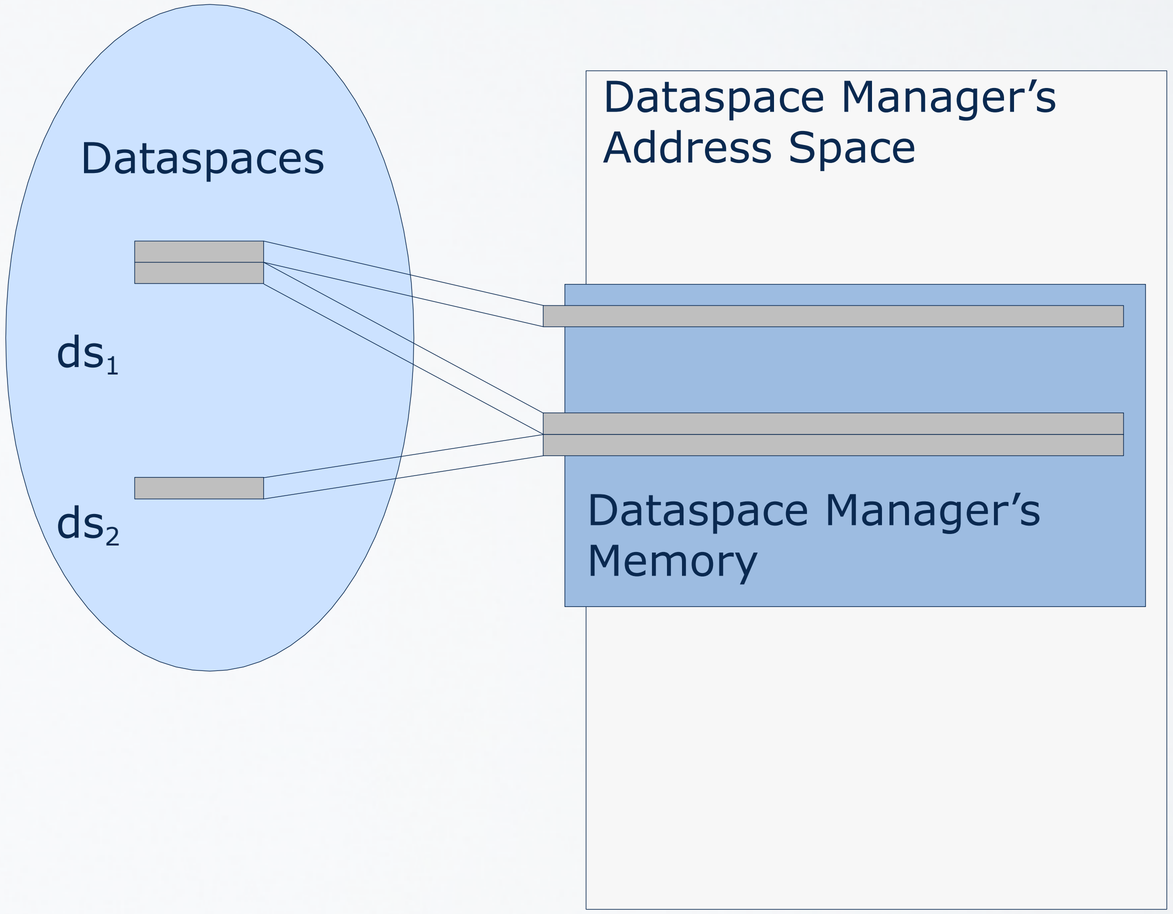
DATASPACES

- Dataspace: *unstructured data container*
- Abstraction for anything that contains data:
  - Files
  - Anonymous memory
  - I/O adapter memory
  - …
- Dataspaces are implemented by *Dataspace Managers*
- Dataspaces can be attached to regions of an address space

DS MANAGER

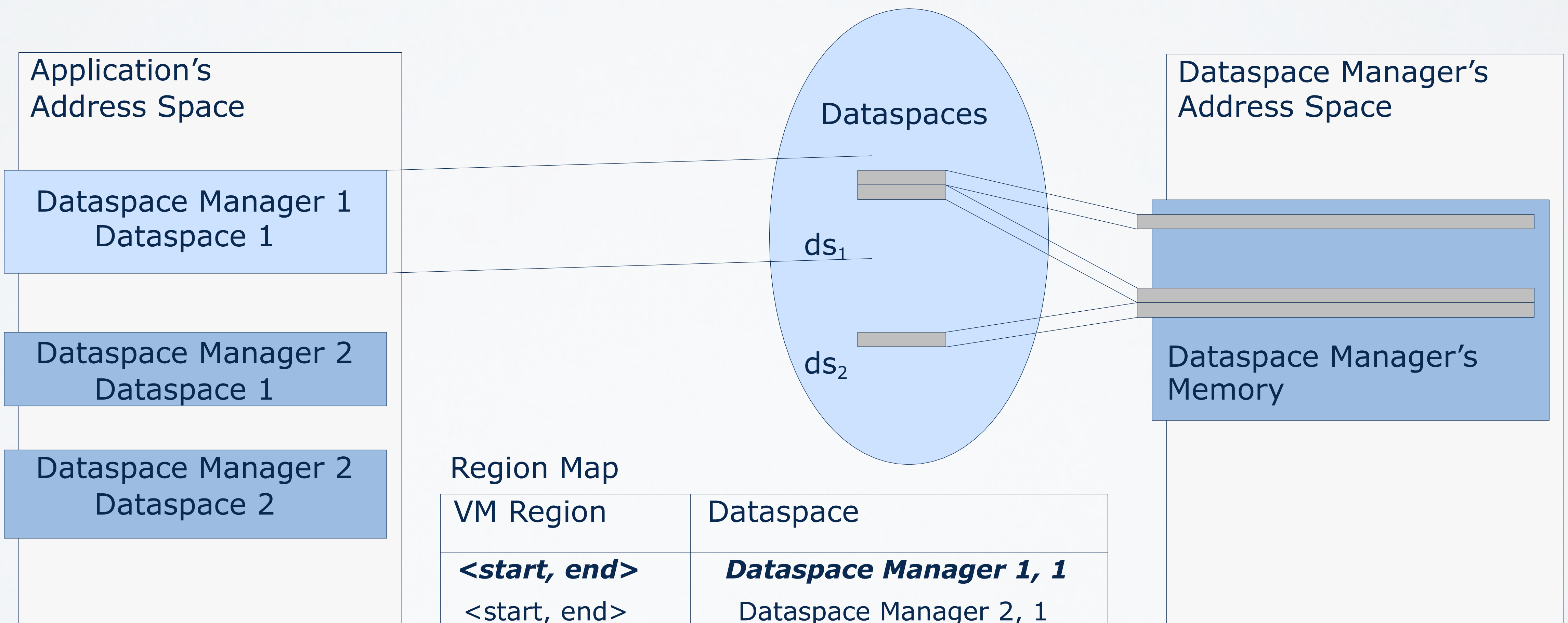
- DS Manager determines the semantic of a dataspace
- Each DSM is the pager for its dataspaces

→ Implements the paging policy (page replacement etc.)



DS & REGIONS

- Region map keeps track which dataspaces are attached to which virtual memory regions
- Region manager translates page faults to dataspace offsets



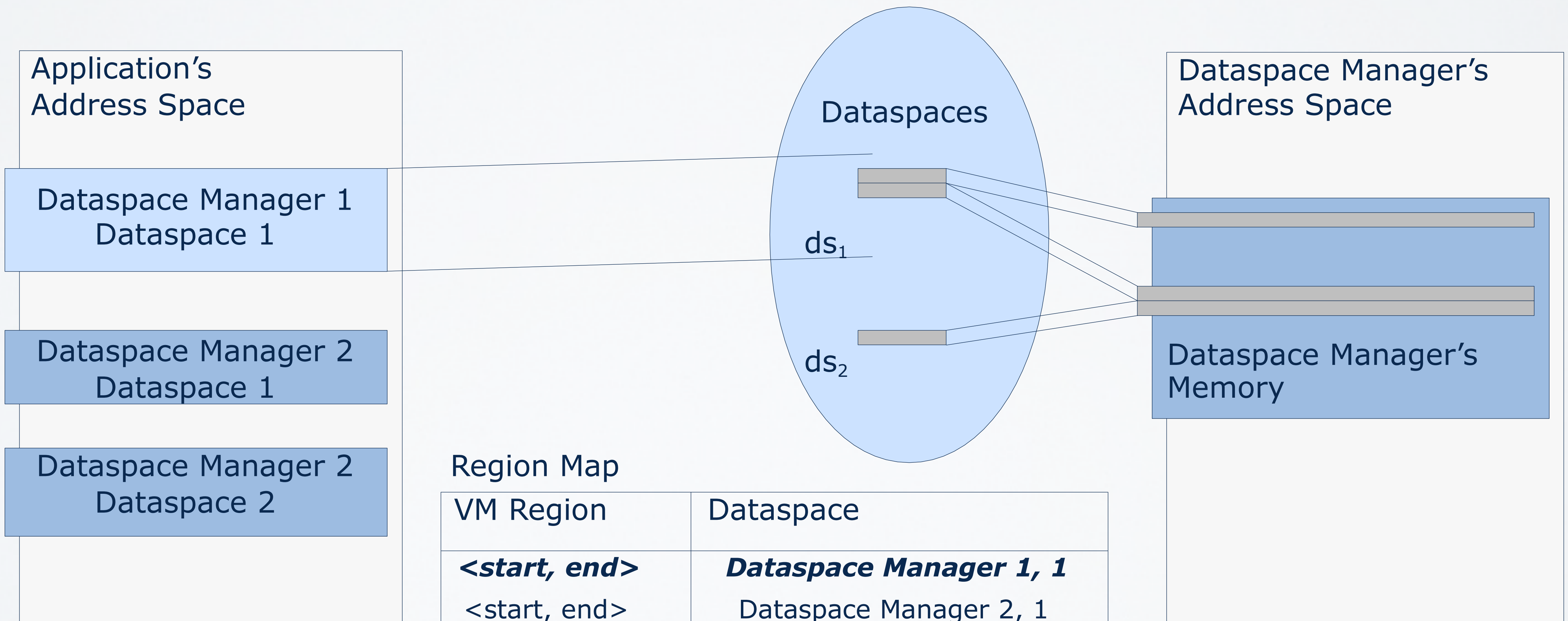
Region Map

VM Region	Dataspace
<start, end>	***Dataspace Manager 1, 1***
<start, end>	Dataspace Manager 2, 1
<start, end>	Dataspace Manager 2, 2

DS & REGIONS

- Region manager propagates fault to dataspace manager's fault handler

➔ Dataspace fault (ds_manager_id, ds_id, offset)



Region Map

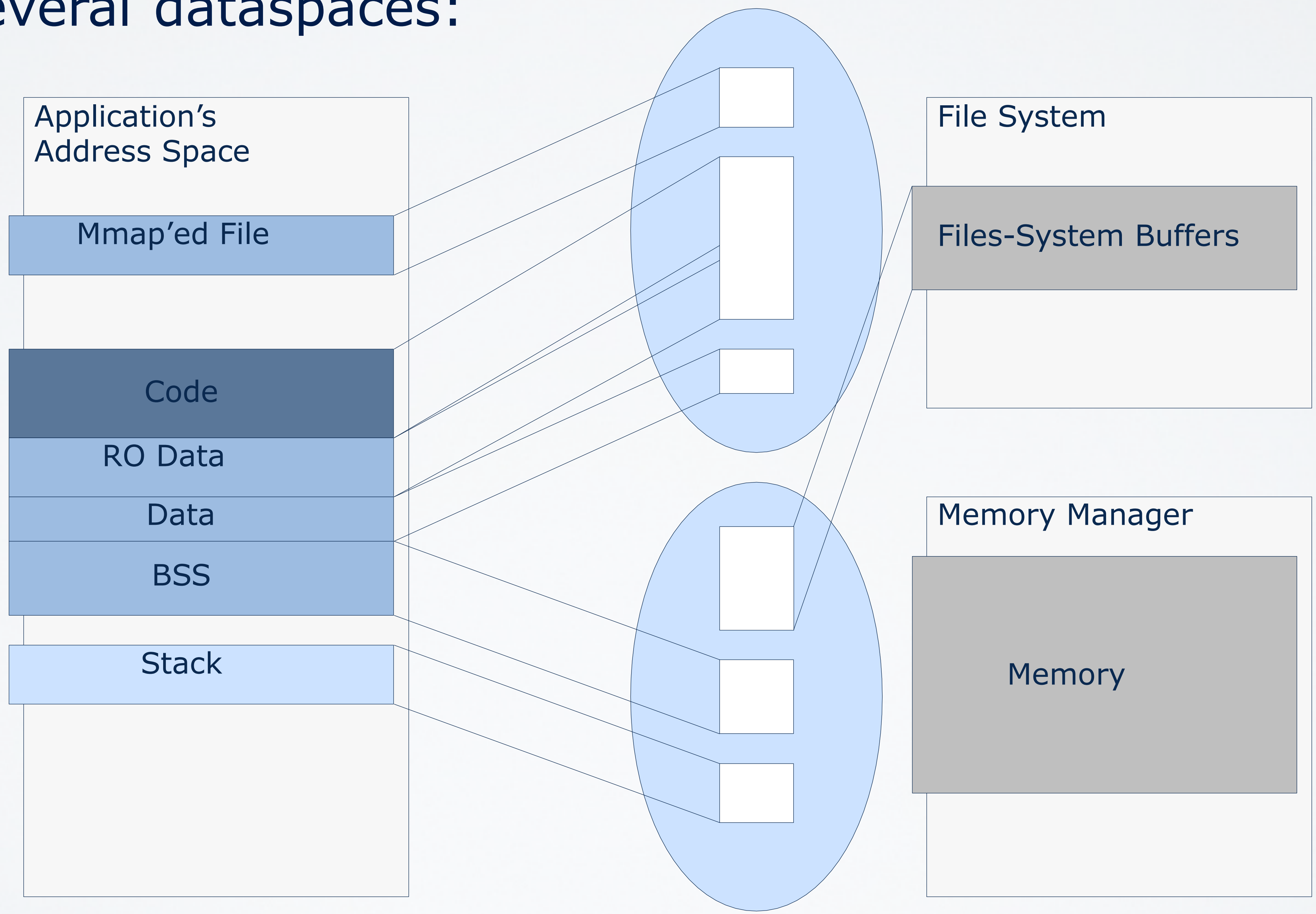
VM Region	Dataspace
<start, end>	***Dataspace Manager 1, 1***
<start, end>	Dataspace Manager 2, 1
<start, end>	Dataspace Manager 2, 2

APPLICATION VIEW

- allocate / free dataspaces
  - create / destroy dataspace
  - semantic depends on dataspace type:
    - anonymous memory: open (size)
    - file: open (filename, mode, …)
    - ...
- attach / detach dataspace
  - create / remove entry in region map
  - → Makes dataspace contents accessible to application
- propagate capability
  - grant access rights to other applications
  - → very easy shared memory implementation

ADDRESS SPACE

- Application address spaces are constructed from several dataspaces:



FURTHER ISSUES

- Page Allocation Algorithms
  - List-based algorithms, bitmaps, trees, …
- Page Replacement Algorithms
  - Least-Recently-Used (LRU)
  - Working Sets
  - Clock
  - …

→ Page allocation and replacement are implemented by dataspace managers

→ Can have different strategies for the dataspaces of an application

MEMORY SHARING

- Memory sharing important for
  - Shared libraries
  - Data transfer between system components
  - …
- Different types of sharing
  - Full sharing: all clients see modifications
  - ➔ easy to implement, pager / dataspace manager grants access rights to pages / dataspaces
  - Lazy copying of dataspaces
  - ➔ copy-on-write

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SUMMARY

- Closer look on tasks/threads:
  - Creation
  - Page-fault handling
- Flexpages
  - Memory pages, I/O ports, Capabilities
  - Structure
  - Offset computation
- Pager hierarchy
- Region manager & dataspaces

MORE INFO

- Flexpages

  H.Härtig, J.Wolter, J.Liedtke: "*Flexible sized page objects*" , http://os.inf.tu-dresden.de/papers_ps/flexpages.pdf

- Dataspaces

  Mohit Aron, Yoonho Park, Trent Jaeger, Jochen Liedtke, Kevin Elphinstone, Luke Deller: "*The SawMill Framework for VM Diversity*", ftp://ftp.cse.unsw.edu.au/pub/users/disy/papers/Aron_PJLED_01.ps.gz