MPTEE: Bringing Flexible and Efficient Memory Protection to Intel SGX

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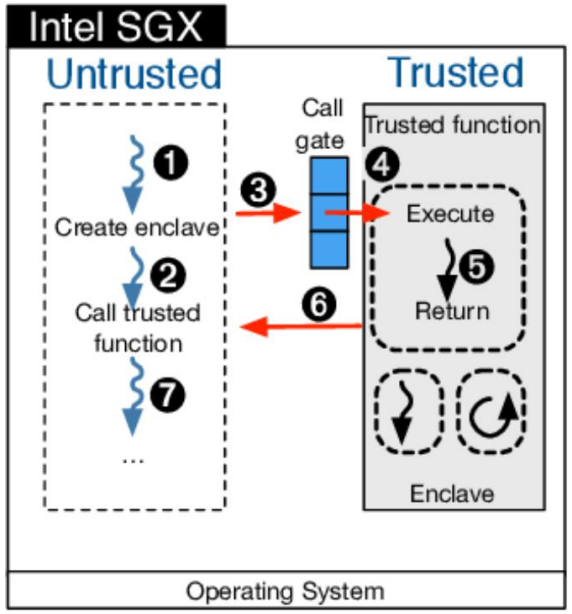
Background

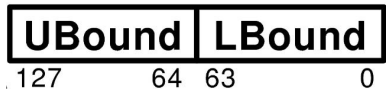
➢ Inter SGX

- Software Guard Extension
- Enclave Cache Page



➢ Intel MPX

- Memory Protection Extensions
- Four bound registers (BND0 ~ BND3)

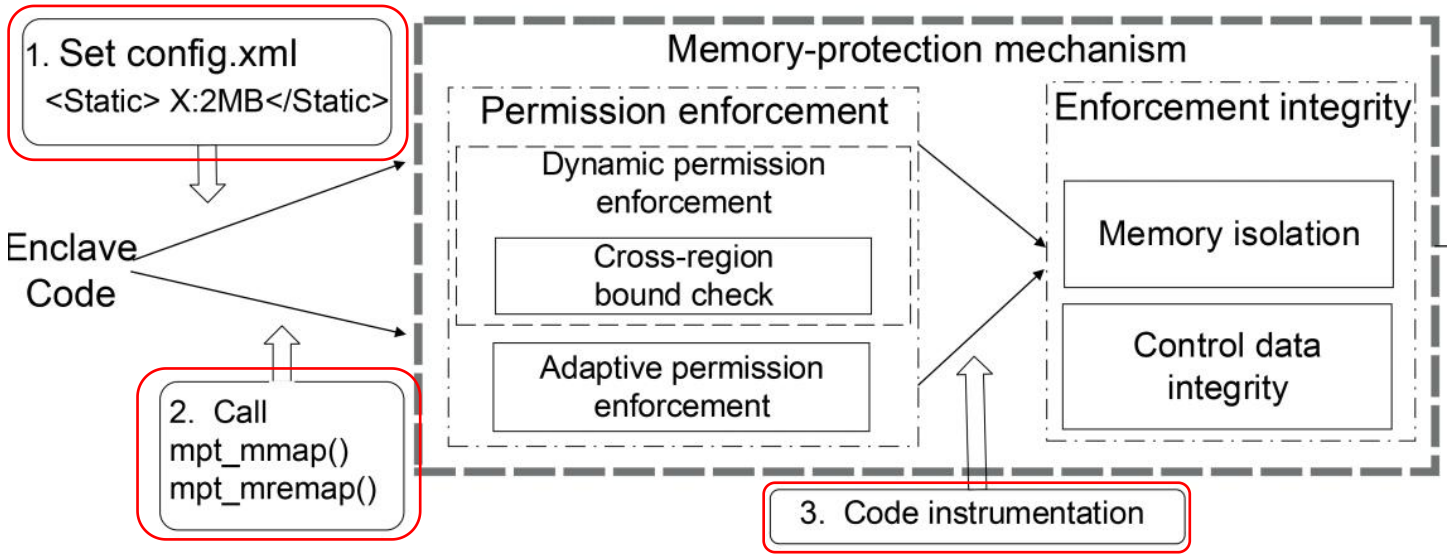


Motivation

- **Need of Flexible memory protection**
  - Dynamically update memory-page permissions
  - Least-privilege principle & Security
- **Existing System**
  - SGX: SECS & Signature-Verifcation mechanism
  - SGX-Shield: R15 Register & SGXCrypter: OS page table
  - MPX: Just four registers
- **Challenge**
  - Limited hardware support
  - Strong adversary

Architecture

➢ MPTEE



➢ Permission Enforcement
- Dynamic
- Adaptive

➢ Enforcement Integrity (EI)
- Memory isolation
- Control-data integrity (CDI)

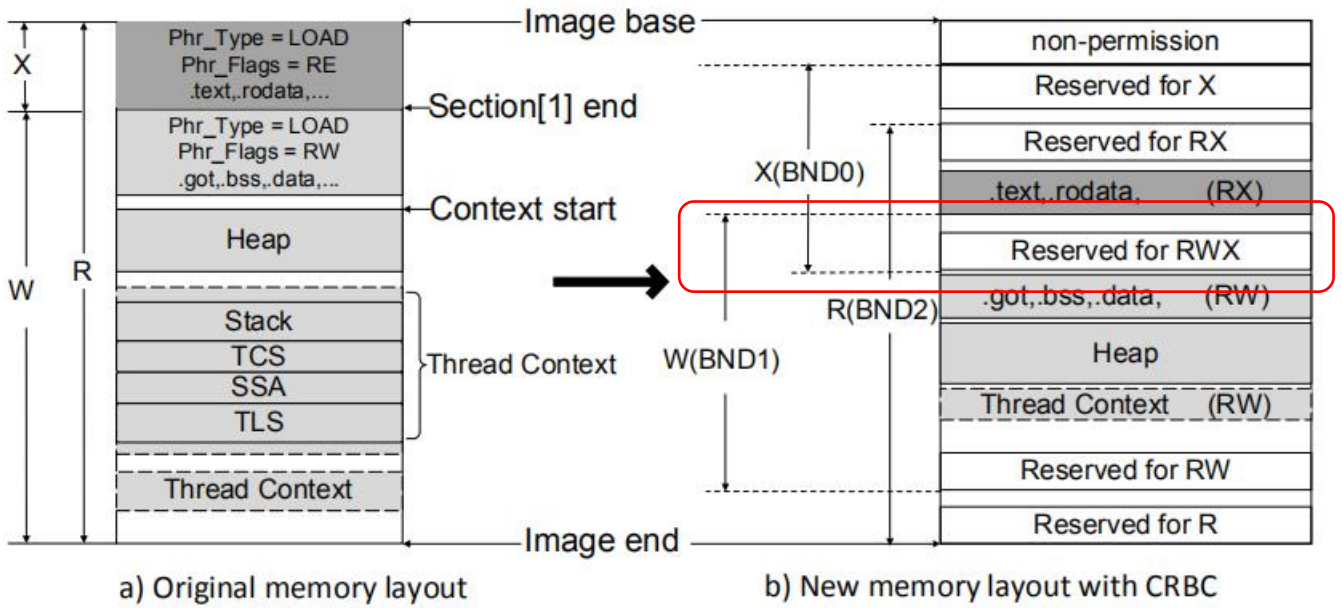
A memory-protection mechanism
Flexible and Efficient enforcement of memory-page permissions in SGX.

Permission Enforcement

Permission	Bound range
non-perm.	(ImageBase, bnd0.lb)
X	(bnd0.lb, bnd2.lb)
RX	(bnd2.lb, bnd1.lb)
RWX	(bnd1.lb, bnd0.ub)
RW	(bnd0.ub, bnd1.ub)
R	(bnd1.ub, bnd2.ub)

Overlapping

➢ Cross-Region Bound Check*



a) Original memory layout

b) New memory layout with CRBC

➢ Unique memory layout of enclaves

- Memory sections that have same permissions are adjacent

➢ Cross-region bounds

❶ BND0 ~ BND2 (Three Registers)

❷ X/R/RX/RW/RWX/No (Six permissions)

❸ RWX - RW: bnd0.ub decrease

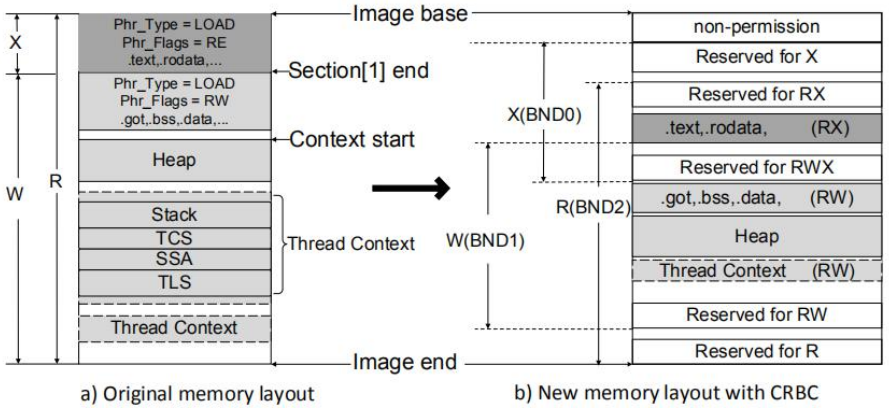
Permission Enforcement

➢ Cross-Region Bound Check*

API	Description
void *mpt_mmap(size, flags)	Acquires a memory buffer, which is at least *size* bytes. It is restricted as specified in *flags*.
void *mpt_mremap(pages, size, flags)	Changes *old_pages* to *flags*. If the *pages* are located at a region boundary, it changes the permissions; otherwise, it allocates new memory buffer and copy content over.
void *mpt_munmap(pages)	Frees an acquired memory buffer, the freed memory will be sealed and swapped out.
void *mpt_write(pages, size, content)	Writes *content* to the mapped region. The function will not be bound-checked.

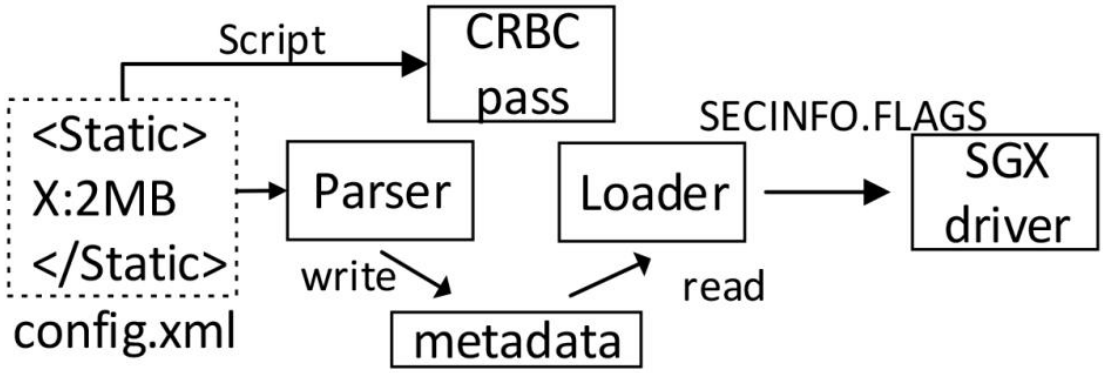
➢ Four APIs

- mpt_mmap() for accquire memory
- mpt_mremap() for change permission



Permission Enforcement

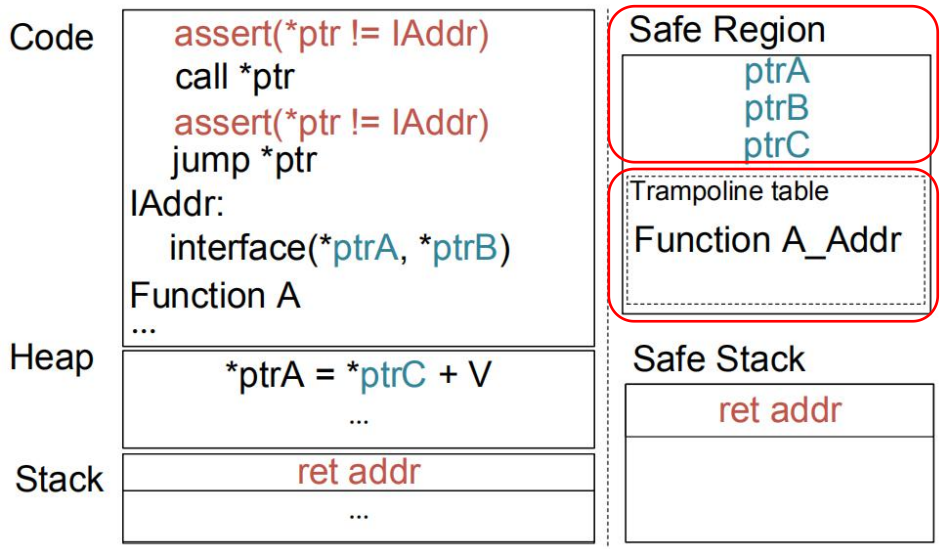
➢ Adaptive Permission Enforcement



- ➢Setting the static region in config.xml
- ➢<Permission>:<Region size>
- ➢CRBC pass: Reduce the performance overhead

Enforcement Integrity

➢Memory Isolation



➢Safe Region

- Protect code and data for permission enforcement
- No-permission region

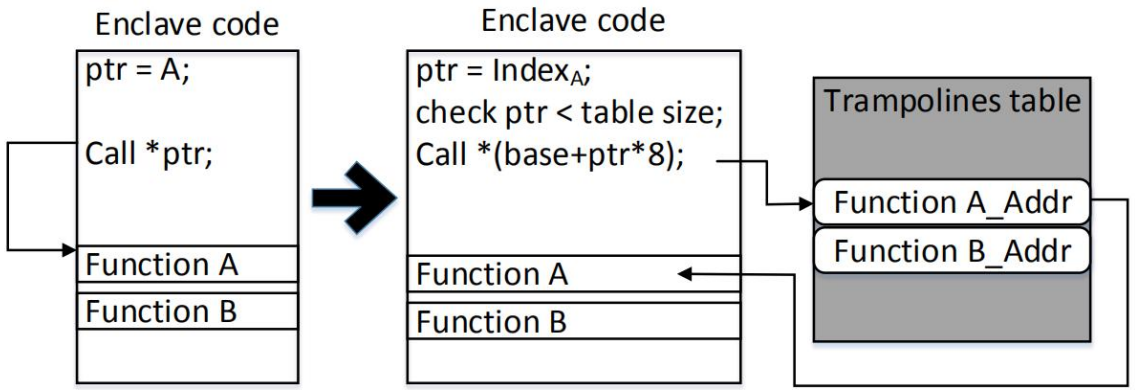
➢Safe Stack & Trampoline table

- Ensure the integrity of return addresses and function pointers

➢Safe Region & Trampoline table

Enforcement Integrity

➢Control-Data Integrity



➢Trampoline table

- protect pointers for indirect calls and jumps

➢Static analysis: All functions whose addresses are ever taken

Evaluation

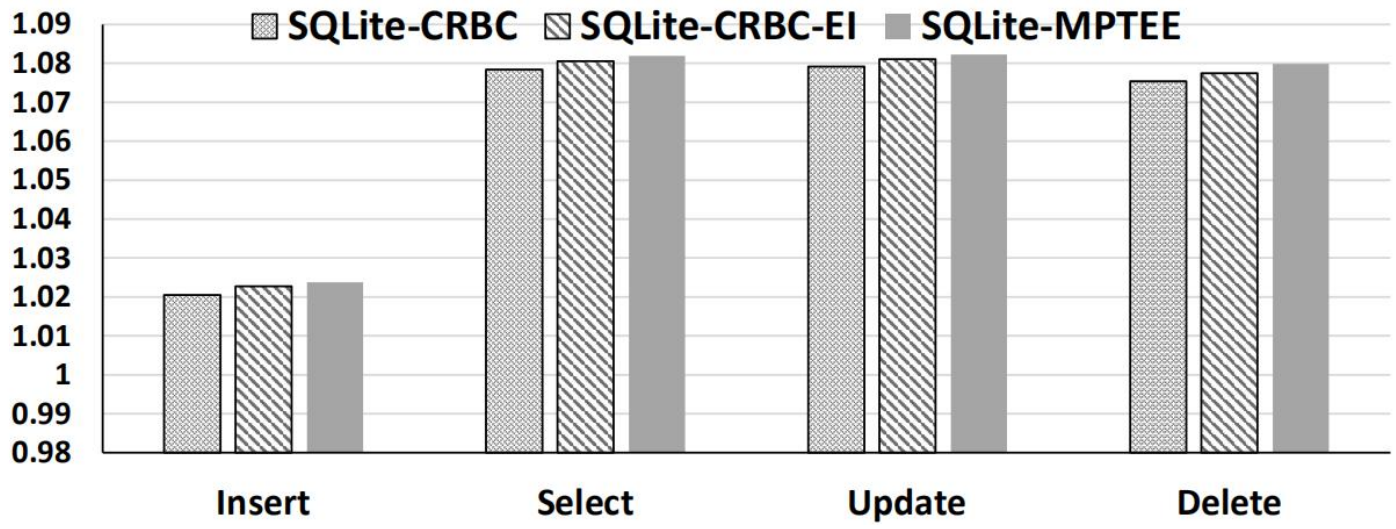
- **Experiments**
  - Dell workstation
  - Intel Xeon E3-1225v5 CPU & 8G RAM
  - Ubuntu 16.04 Server

- **Evaluation**
  - Performance
  - Utility Analysis
  - Security Analysis

Evaluation

SQLite is a C-language library
Implements small and fast SQL database engine.

➢Performance



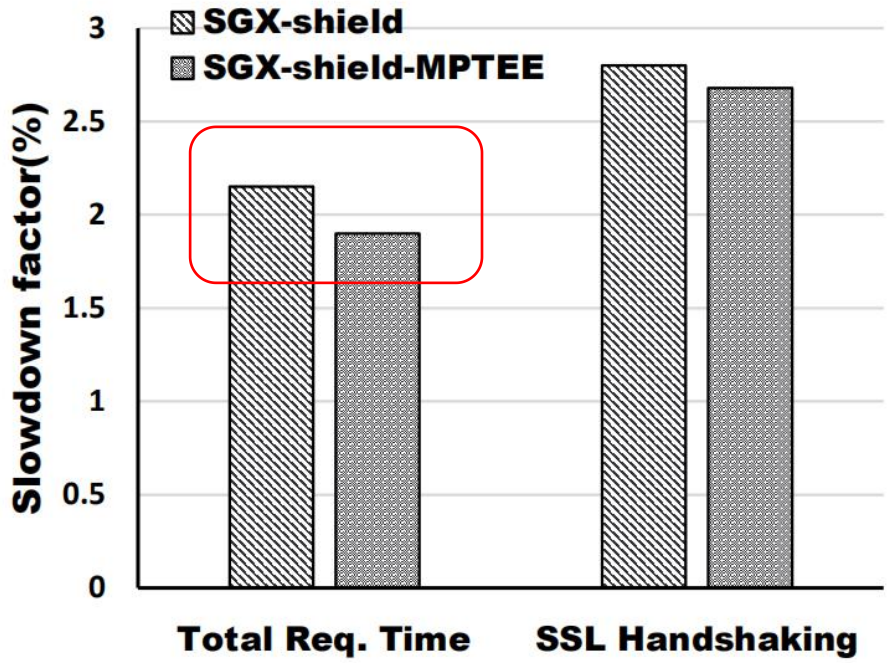
Low overhead imposed by MPTEE

- ➢CRBC imposes 2%–7% (avg 6.6%) overhead
- ➢EI imposes smaller than 1%
- ➢More frequent memory accesses leading to more bound checks.

Evaluation

Requesting HTML fles from the HTTPS server

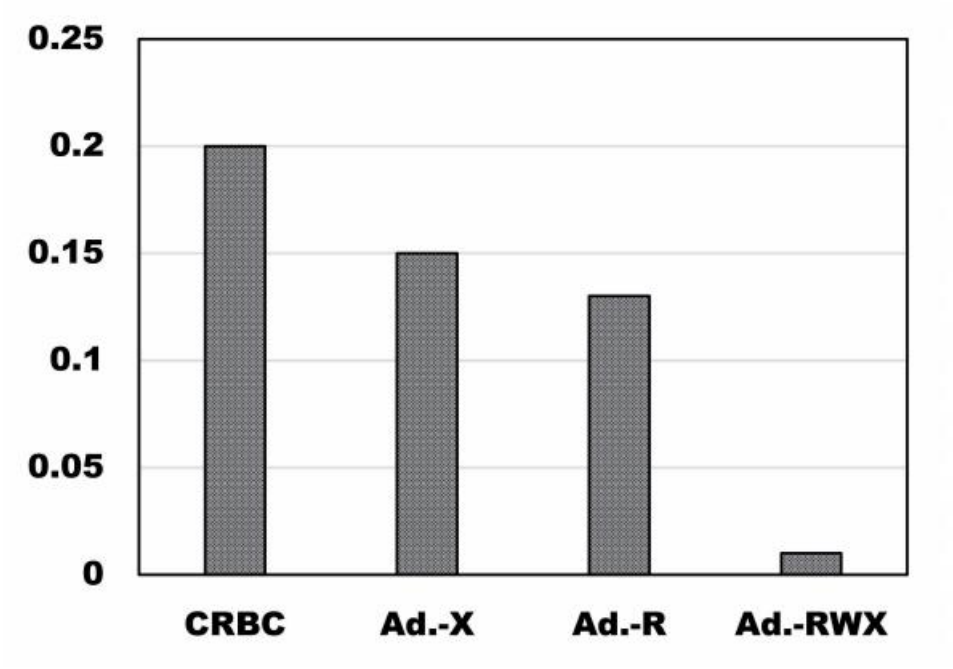
➢Performance



- ➢SGX-Shield-MPTEE has lower overhead 1.9%
  (with no adaptive permission)
- ➢SGX-Shield is 2.2% & Only provide one permission

Evaluation

- **Performance**



Benefts from adaptive permission enforcement

- CRBC incur up 20% overhead
- Adaptive-RWX incurs almost 0% (hardware)
- Bound-checking of R is more frequent than X

Evaluation

➢Utility Analysis

- Confrm MPTEE is easy-to-use and practical
- SGX-Shield NRW boundary
  - mpt_mmap(sgx_end-sgx_start, X)
- Protecting SGX-Shield code

Evaluation

➢Threat Model

- Trusted: only Intel SGX itself
- Untrusted: All other software and hardware components
- Vulnerabilities of code running inside SGX: buffer overfows

➢Security Analysis

- Check-skipping attacks: CDI
- Bound-manipulating attacks: Memory Isolation

Conclusion

- **MPTEE**
  - Cross-Region Bound Check
  - Adaptive Permission Enforcement
  - Memory Isolation & Control-data Integrity
- **Evaluation**
  - Performance
  - Utility & Effectiveness.

MPTEE can achieve a flexible and secure memory protection while just imposing a small overhead

Comments

➢ Advantages

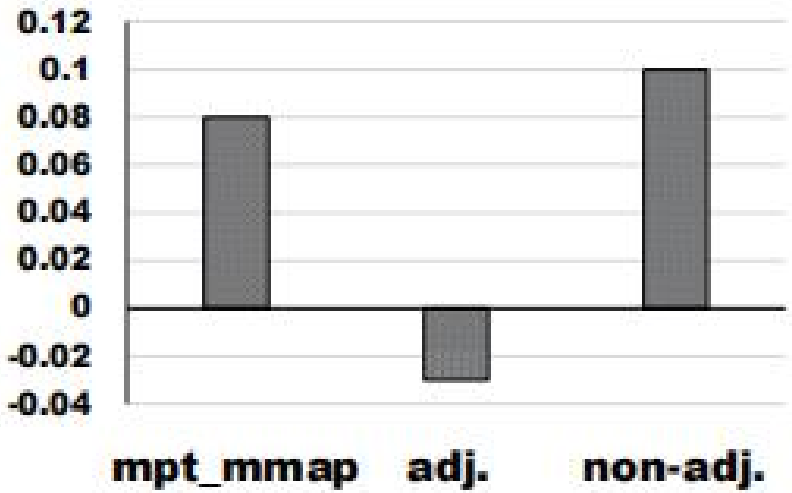
- The MPTEE actually develop a flexible and secure memory-protection mechanism with less hardware support and just impose a small overhead.

➢ Disadvantages

- Intel MPX has been eliminated by Microsoft.
- Argues:
  - As the hardware component, SGX cannot be easily upgraded. Old version SGX will still be the dominating version for a while.
  - For enforcement integrity, MPTEE's design is compatible with new SGX.
- Maintenance burdens

Append

- mpt_mremap()




```
   Input  : addr, size, flags
   Output : new_addr
   Data: Metadata of 5 Reserved region, 3 bnd register
1  Get cur_region, flags_region, neighbor_region from addr and registers
2  if cur_region == flags_region then
3      new_addr = realloc(addr, size)
4      if realloc failed then
5          if neighbor_region is not reserved || neighbor_region has
             allocated then
6              new_add = NULL
7          else
8              Get bndX according to flags_region
9              bndX.lb = bndX.lb + size
10             update metadata of cur_region
11         new_addr = realloc(addr, size)
12 else if cur_region is neighbor with flags_region then
13     Get bndX according to flags_region
14     bndX.lb = bndX.lb - size
15     new_addr = addr
16 else
17     Get the dest_heap according to flags
18     new_addr = malloc in dest_heap
19     mpt_write(new_addr, size, addr)
20     mpt_munmap(addr)
21 return new_addr
```