On-the-Fly Data Race Detection in MPI One-Sided Communication

Presentation – Master Thesis

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Motivation

- Traditional MPI communication model is two-sided
- Modern HPC cluster networking architectures: RDMA
  - Increasing popularity of one-sided communication models
- MPI Remote Memory Access (RMA)
  - Used in implementations of PGAS paradigms
- **Problem:** MPI RMA programming error-prone
- New kind of programming mistakes: **Data Races**

Motivation

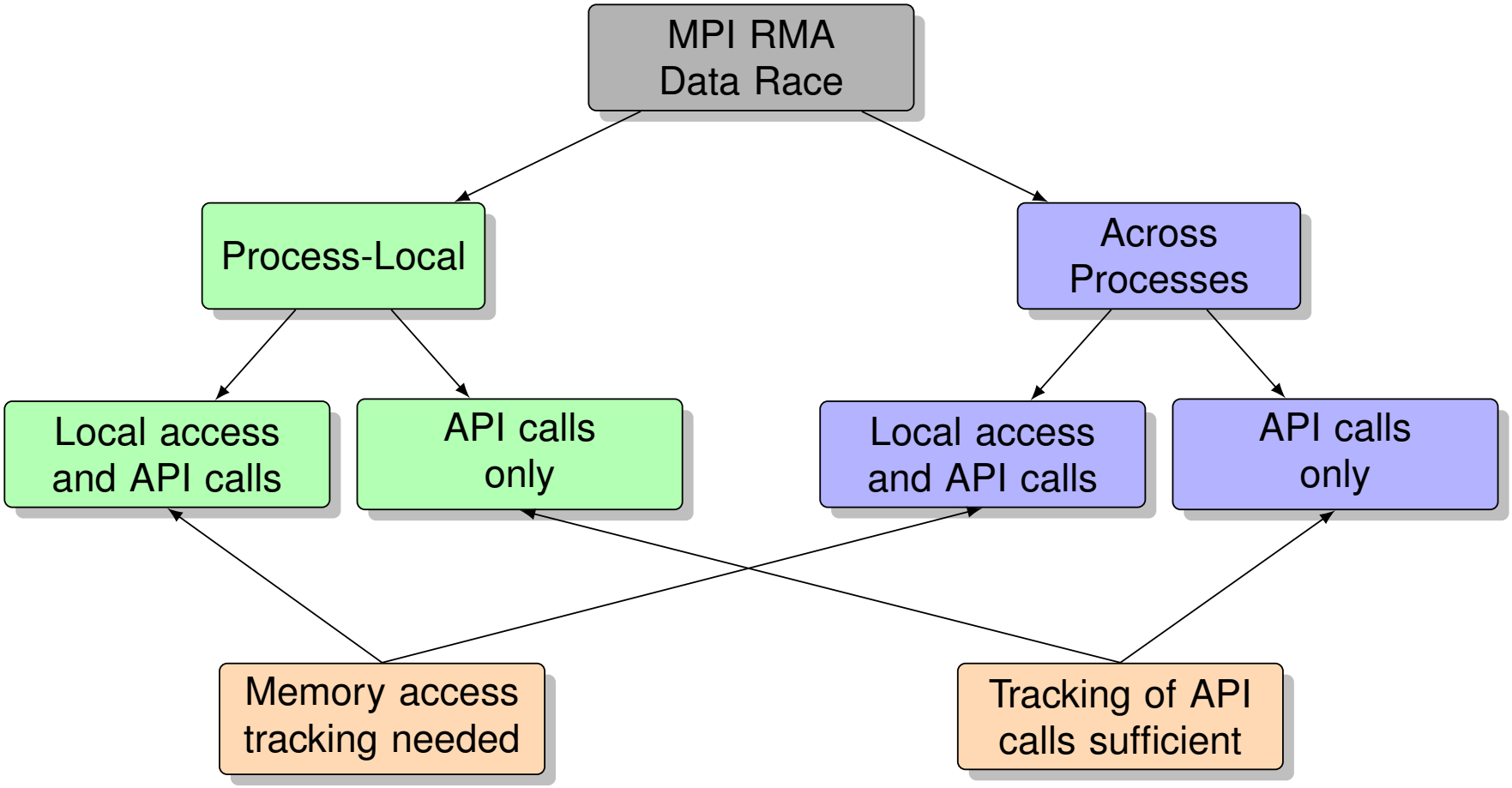
Process A	Process B
	`window location X`
`MPI_Barrier`	`MPI_Barrier`
`MPI_Win_lock(B)`	
`buf = 42`	
`MPI_Put(&buf, B, X)`	`print(X)`
`MPI_Win_unlock(B)`	
`MPI_Barrier`	`MPI_Barrier`

- Data race between process A and B at window location X
- How can we detect such data races?

Thesis Goals

- Classification of data races in MPI RMA
- Development of an on-the-fly data race detection model
- Implementation in correctness checking framework MUST
- Evaluation with different test cases

Data Race Classes



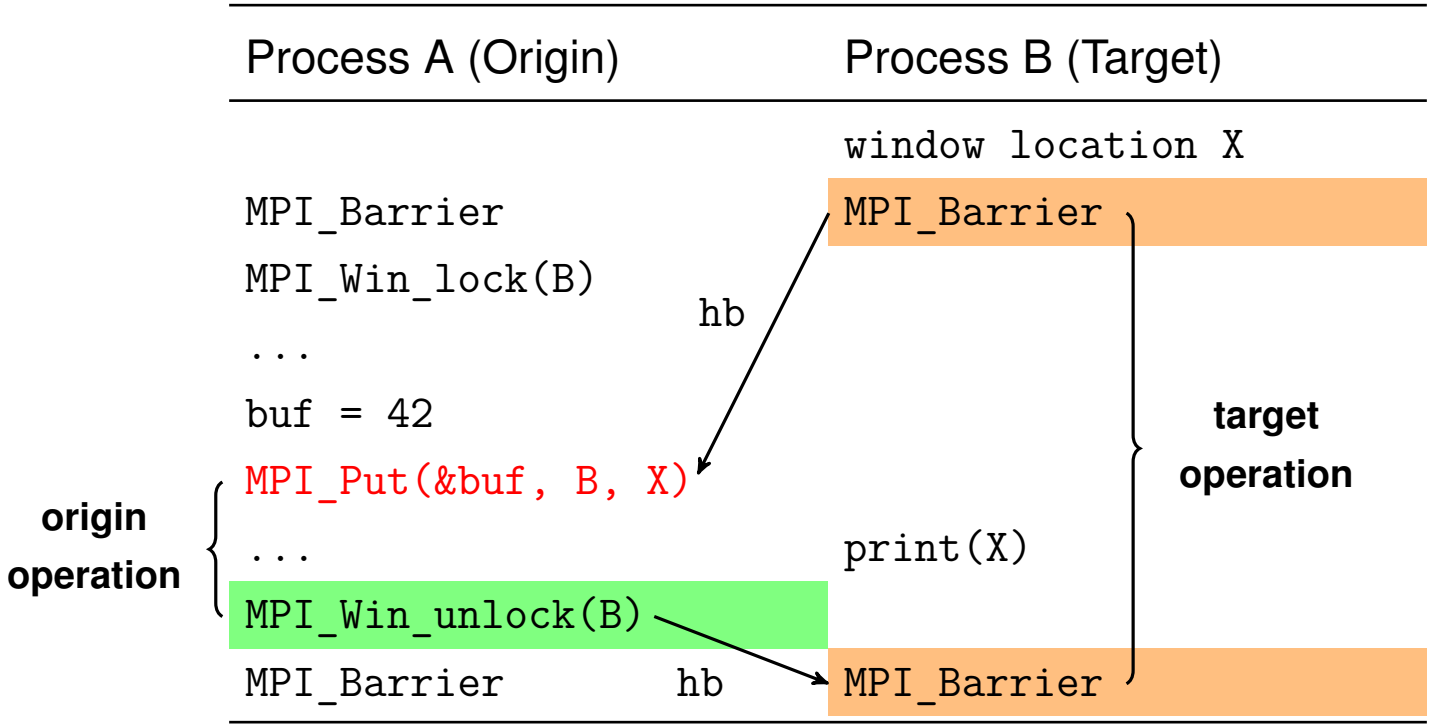
Race Detection – Formalization

- Formalize MPI RMA semantics
  - Hoefler et al. “Remote Memory Access Programming in MPI-3”
  - Track consistency order $\xrightarrow{co}$ (memory synchronization)
  - Track happens-before order $\xrightarrow{hb}$ (process synchronization)

Process A (Origin)	Process B (Target)
	`window location X`
`MPI_Barrier`	`MPI_Barrier`
`MPI_Win_lock(B)`	
`buf = 42`	
`MPI_Put(&buf, B, X)`	`print(X)`
`MPI_Win_unlock(B)`	
`MPI_Barrier`	`MPI_Barrier`

Race Detection – Concurrent Regions

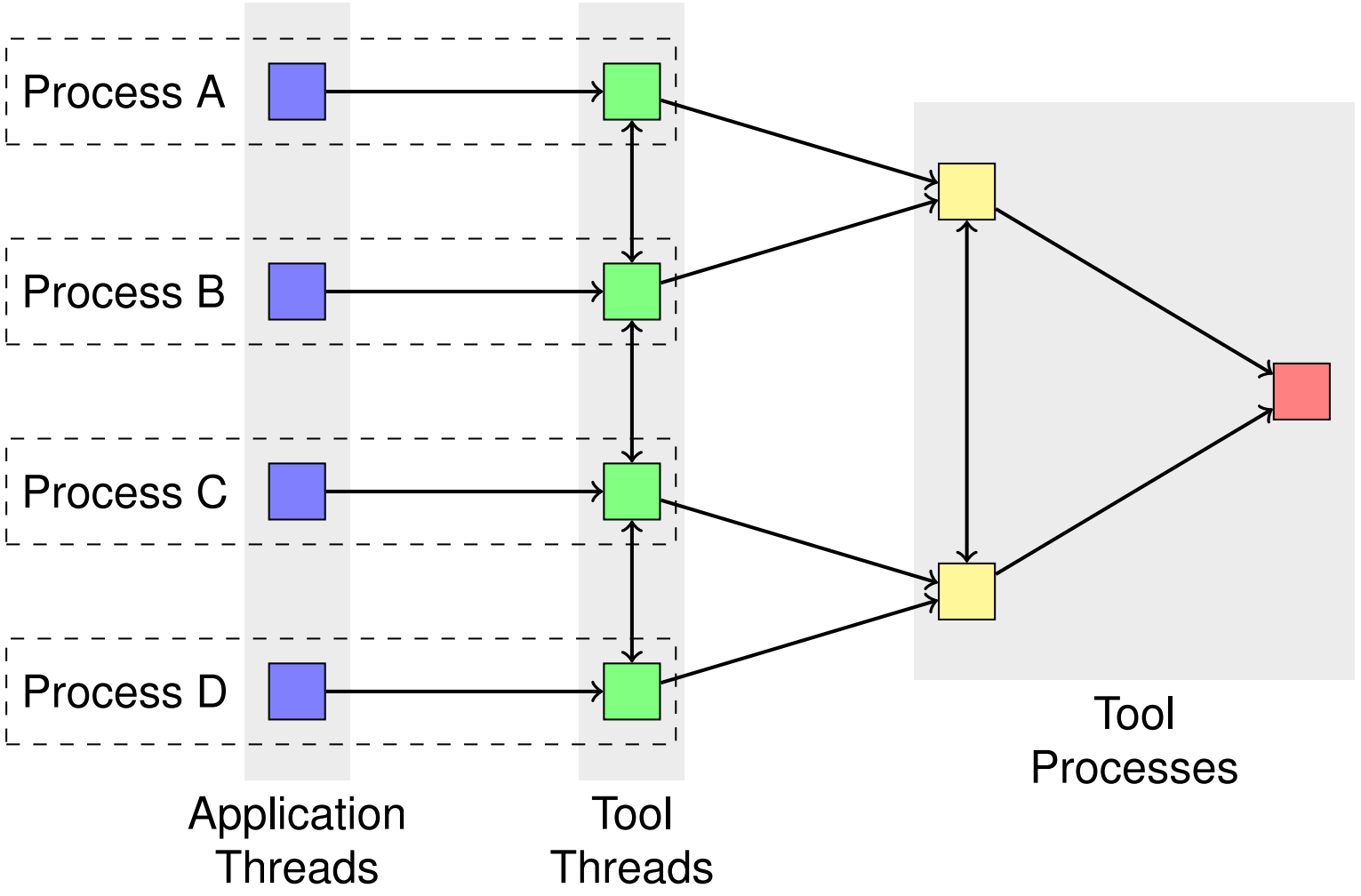
- Local access: Origin operation / Remote access: Target operation
- Identify *concurrent regions* of origin and target operations
  - Cover *earliest* and *latest* point in time when operation can take place



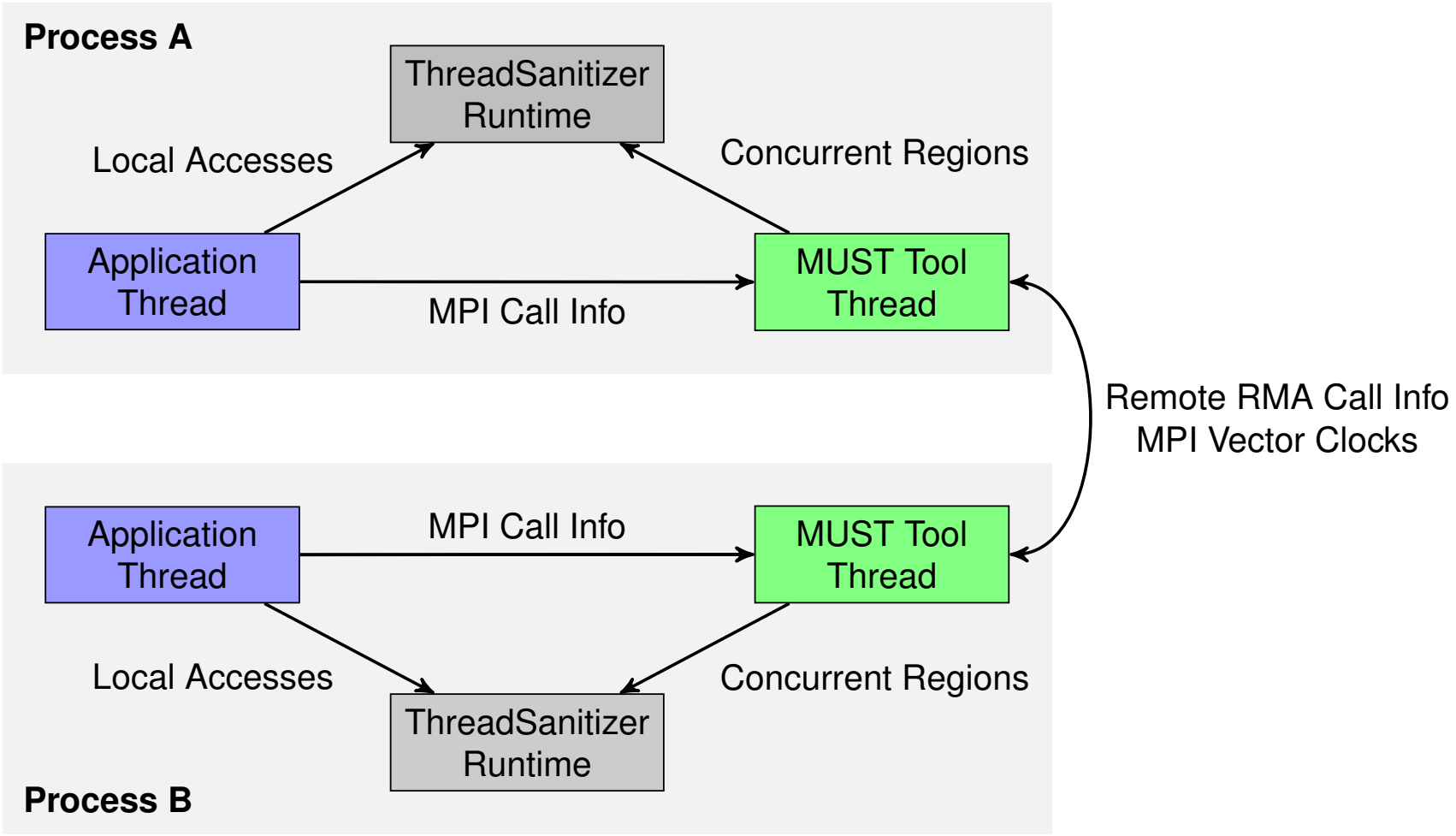
Implementation

- Tracking of MPI calls: MUST correctness checking framework
  - Capture memory and process synchronization in MPI
  - Determine concurrent regions of MPI RMA operations
- Actual data race detection: ThreadSanitizer
  - Runs locally on each process
  - Captures local memory accesses
  - Provides annotation API
- Idea: Annotate concurrent regions in ThreadSanitizer

MUST Infrastructure



Annotations



Conclusion

- MPI RMA introduces one-sided communication model
- Data races in MPI RMA as new error class
- Main concepts of on-the-fly data race detection
  - Tracking memory consistency and happens-before order
  - Identification and annotation of concurrent regions of RMA operations
- Prototype implementation in MUST and ThreadSanitizer
  - Potential of false positives (benign races)
  - Detects representatives of defined data race classes