Lecture 25:

Under the Hood, Part 1: Implementing Message Passing

Parallel Computer Architecture and Programming
CMU 15-418/15-618, Fall 2019

Today's Theme

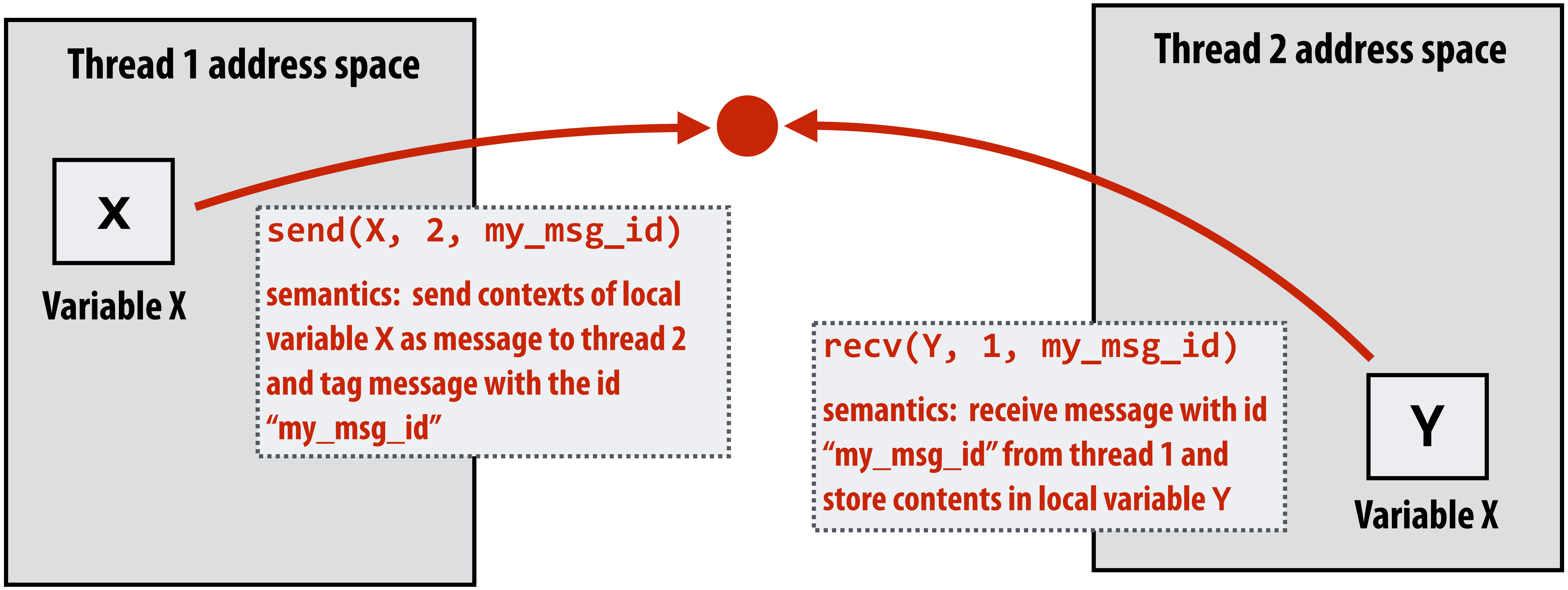
A. Y. OWEN

Teenage Boy Showing the Engine of His First Car, a 1951 Mercury

The LIFE Picture Collection

Message passing model (abstraction)

- Threads operate within their own private address spaces
- Threads communicate by sending/receiving messages
  - send: specifies recipient, buffer to be transmitted, and optional message identifier ("tag")
  - receive: sender, specifies buffer to store data, and optional message identifier
  - Sending messages is <u>the only way</u> to exchange data between threads 1 and 2



`send(X, 2, my_msg_id)`

semantics: send contexts of local variable X as message to thread 2 and tag message with the id "my_msg_id"

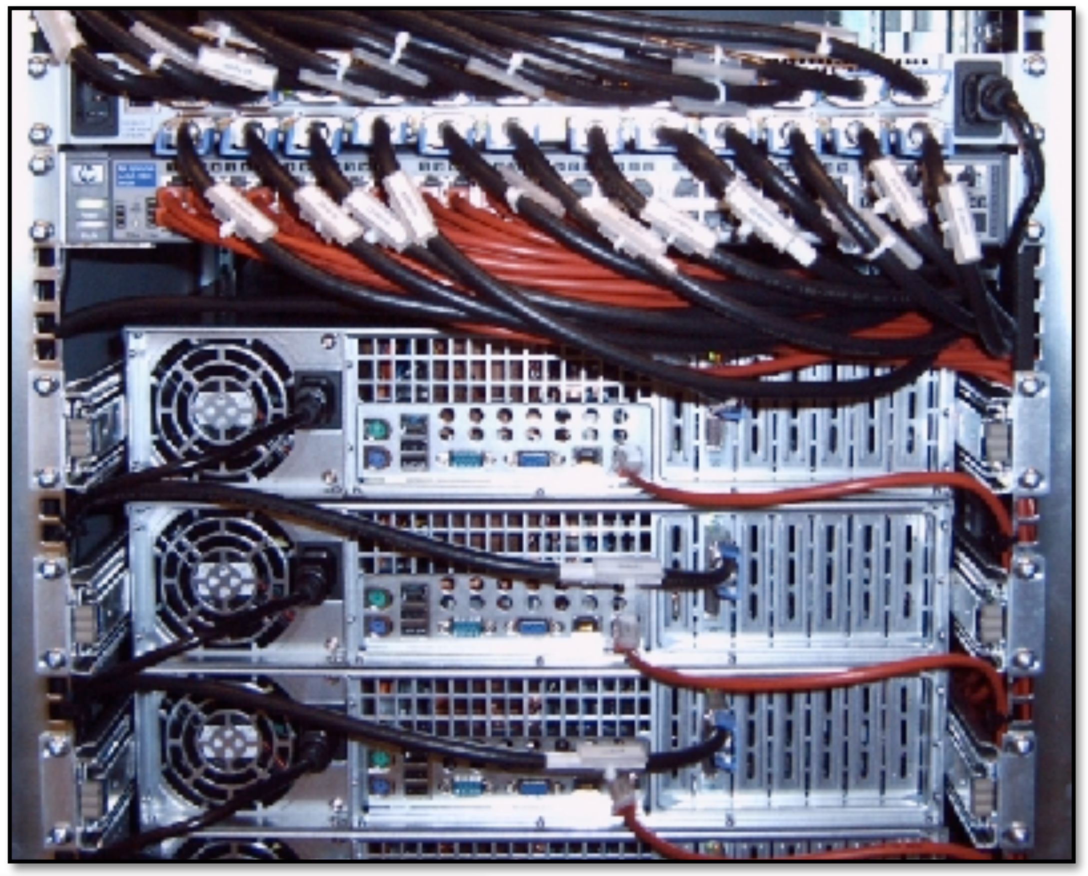
`recv(Y, 1, my_msg_id)`

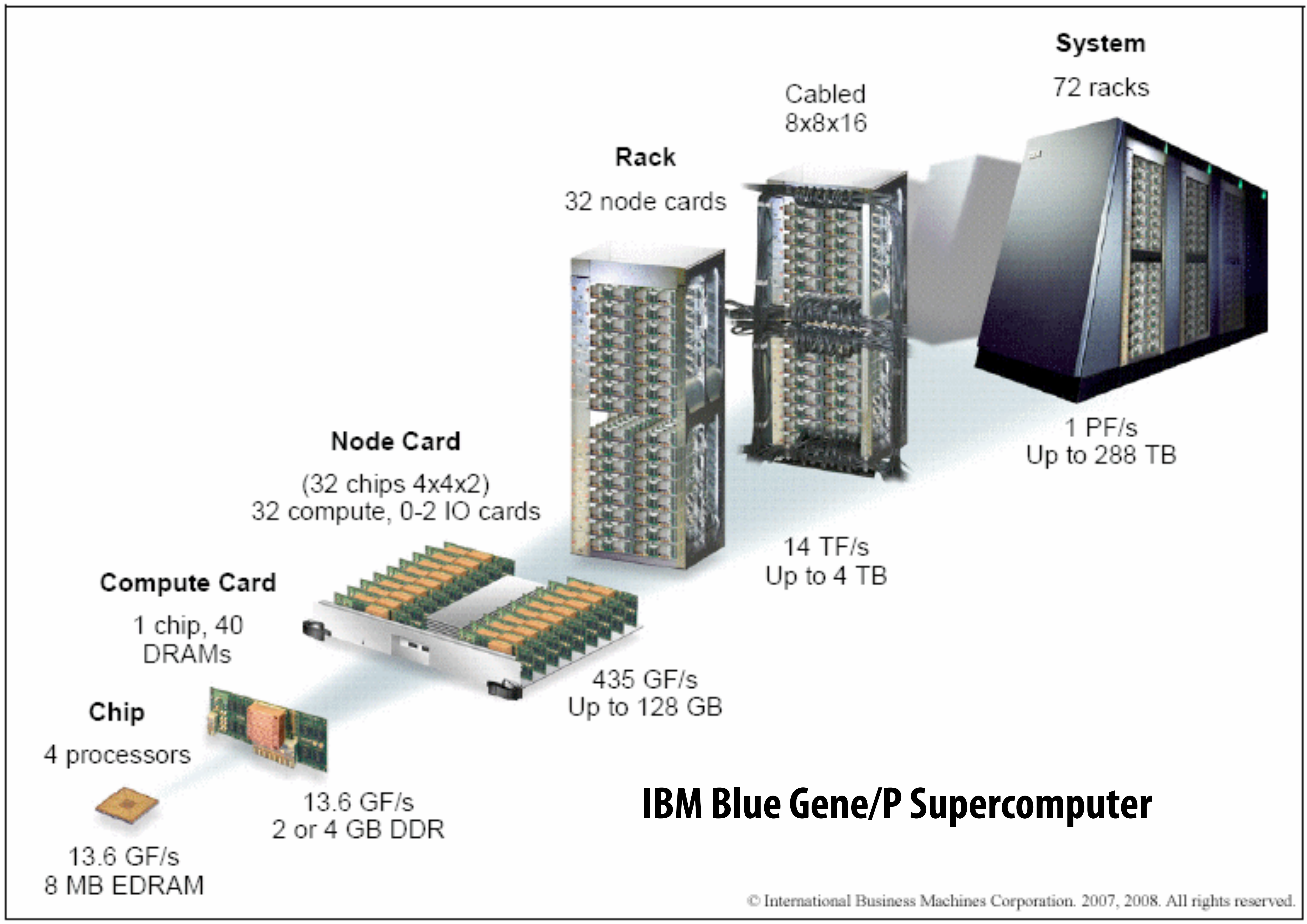
semantics: receive message with id "my_msg_id" from thread 1 and store contents in local variable Y

Illustration adopted from Culler, Singh, Gupta

Message passing systems

- Popular software library: MPI (message passing interface)
- Hardware need not implement system-wide loads and stores to execute message passing programs (need only be able to communicate messages)
  - Can connect commodity systems together to form large parallel machine (message passing is a programming model for clusters)





IBM Blue Gene/P Supercomputer

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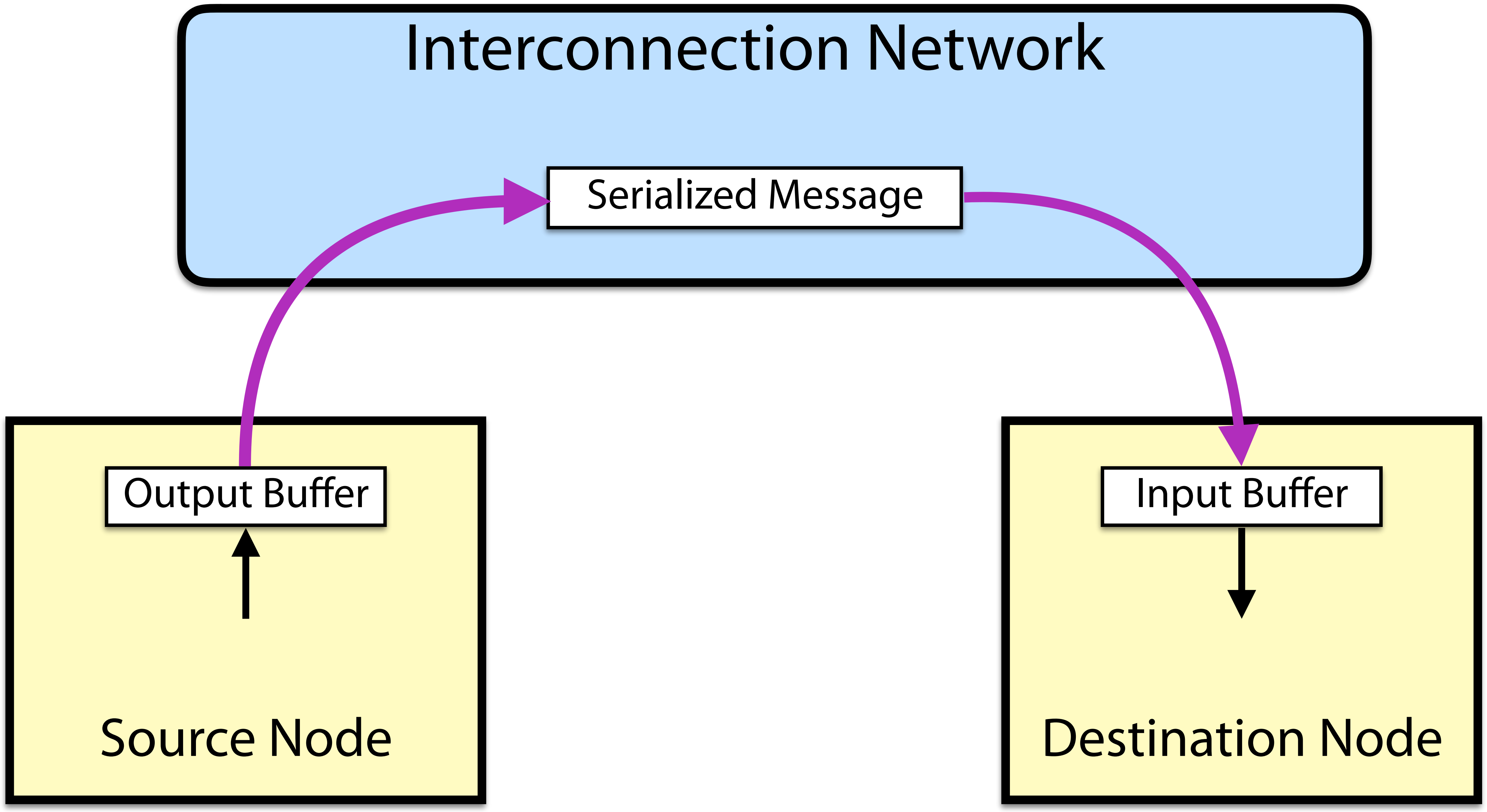
Cluster of workstations
(Infiniband network)

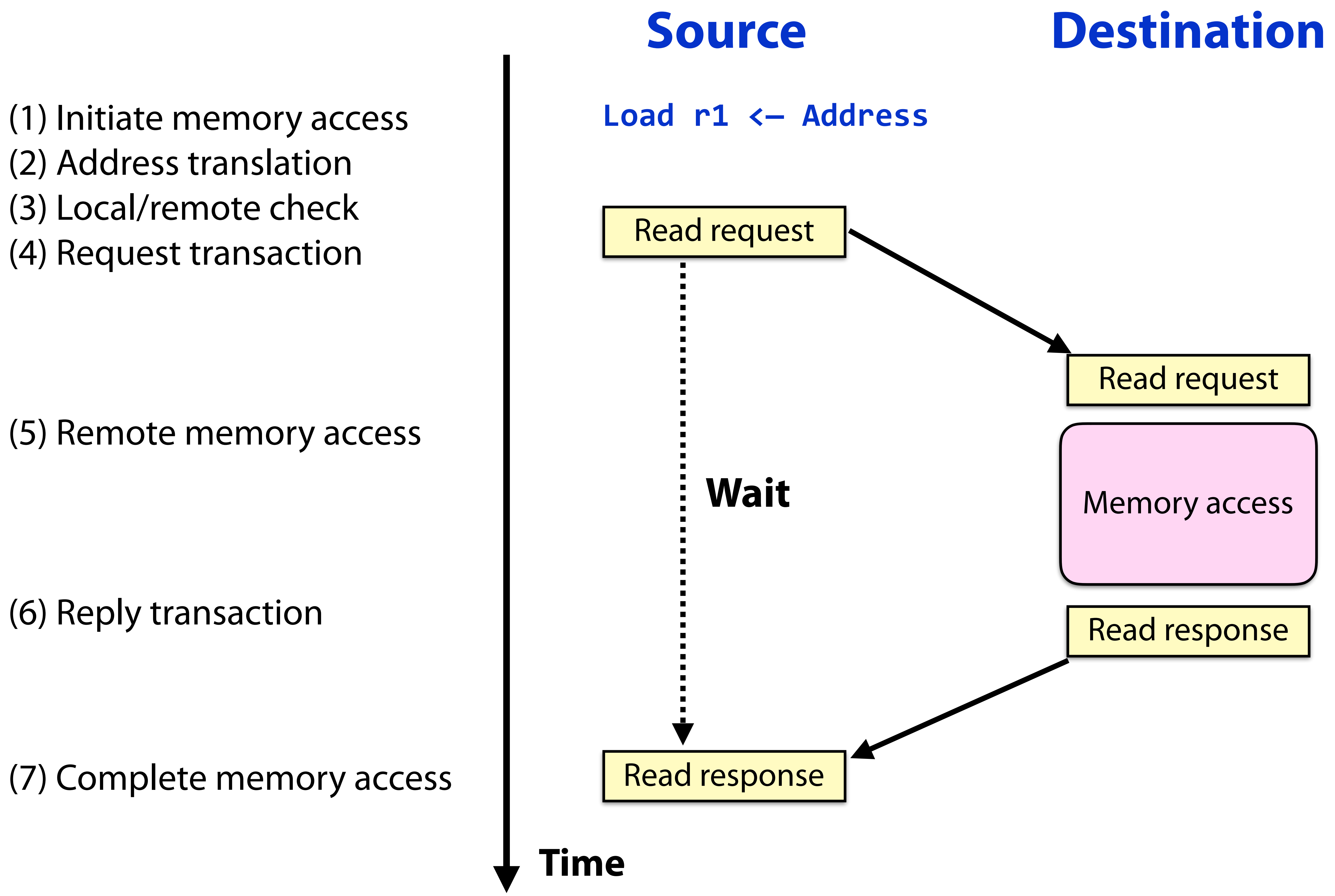
Image credit: IBM

Network Transaction



- One-way transfer of information from a **source output buffer** to a **destination input buffer**
  - causes some action at the destination
    - e.g., deposit data, state change, reply
  - occurrence is not directly visible at source

Shared Address Space Abstraction



- **Fundamentally a two-way request/response protocol**
  - **writes have an acknowledgement**

Key Properties of SAS Abstraction

- Source and destination addresses are specified by source of the request
  - a degree of logical coupling and trust
- No storage logically "outside the application address space(s)"
  - may employ temporary buffers for transport
- Operations are fundamentally request-response
- Remote operation can be performed on remote memory
  - logically does not require intervention of the remote processor

Message Passing Implementation Options

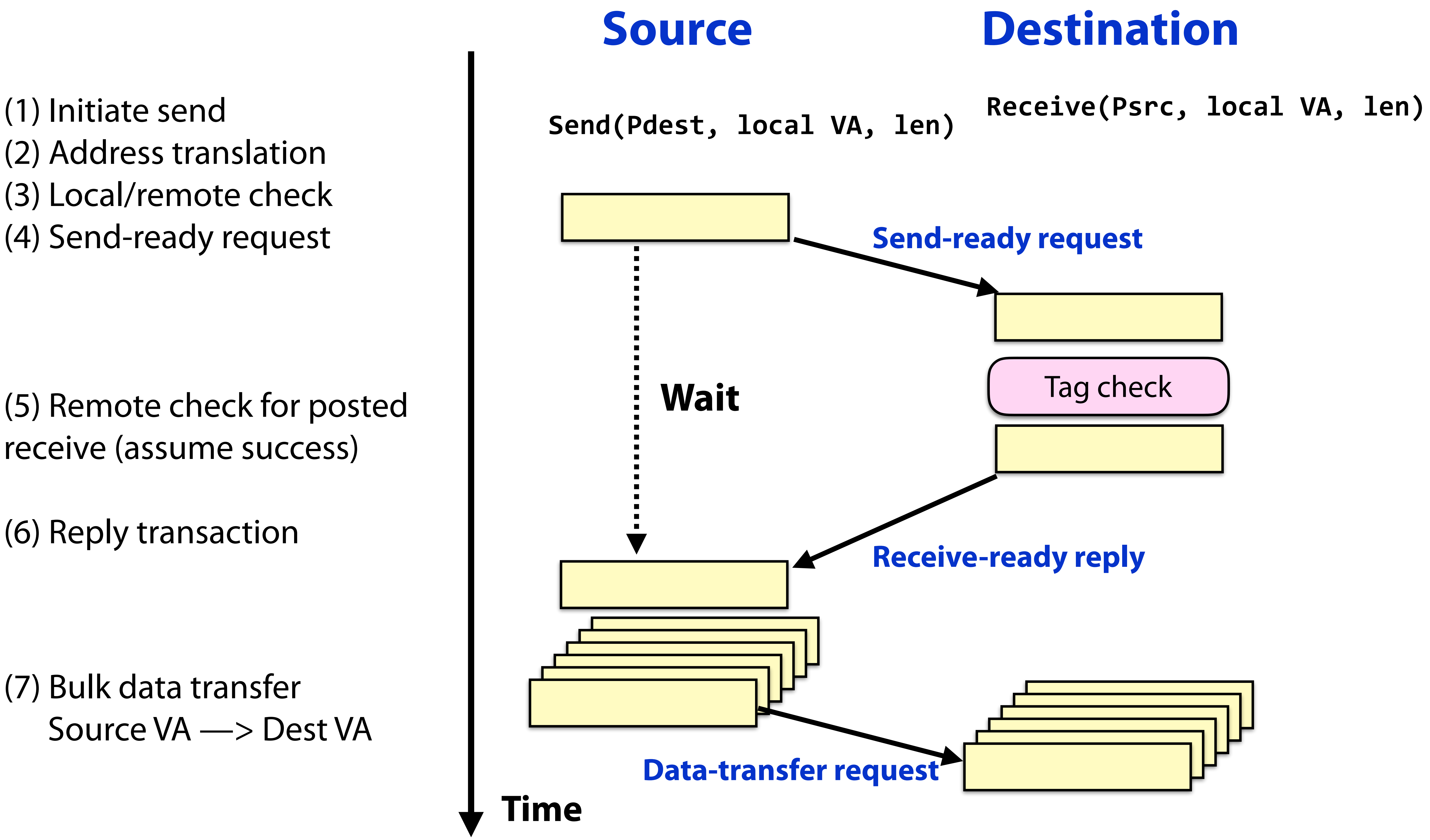
Synchronous:

- Send completes after matching receive and source data sent
- Receive completes after data transfer complete from matching send

Asynchronous:

- Send completes after send buffer may be reused

Synchronous Message Passing

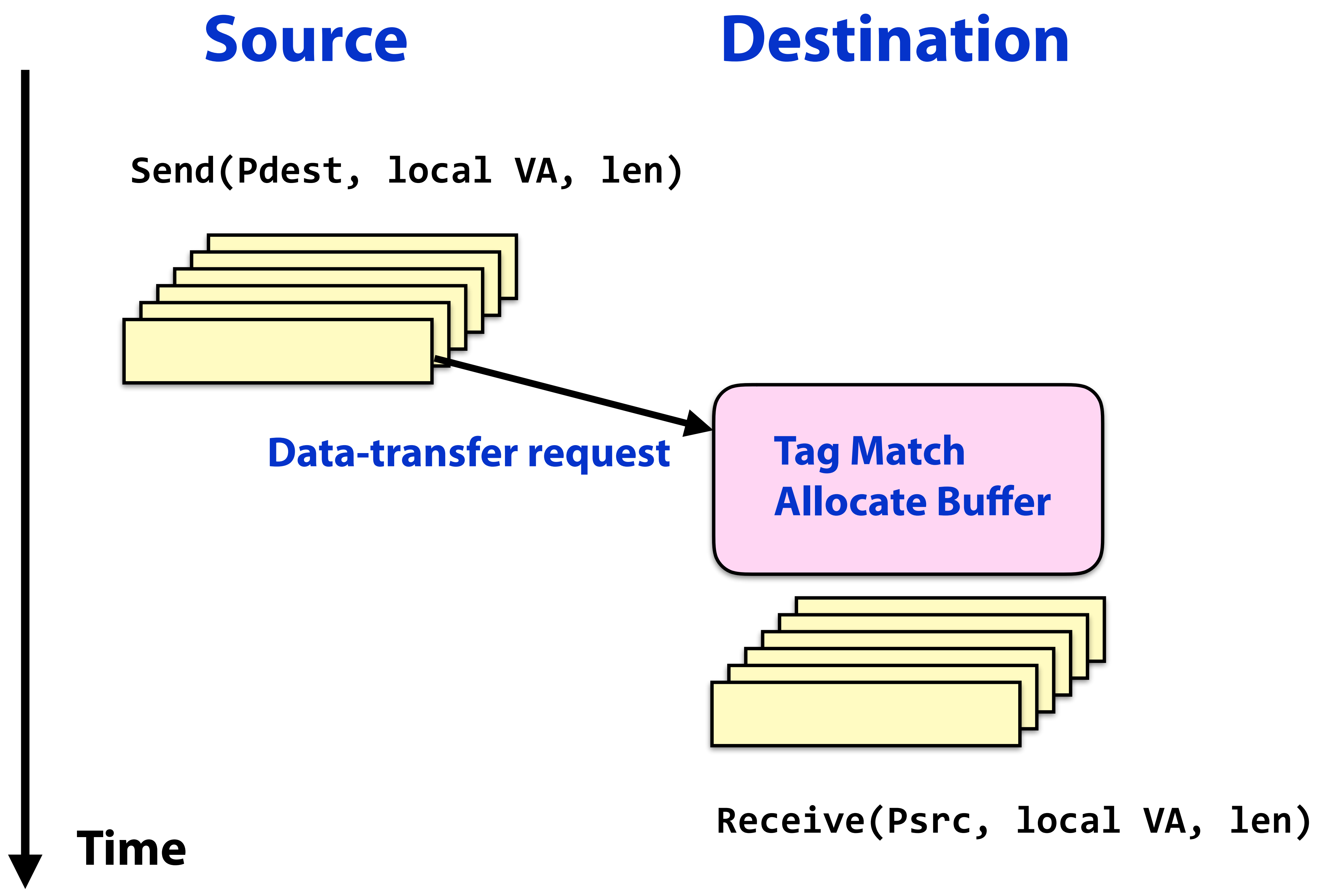


- **Data is not transferred until target address is known**
  - **Limits contention and buffering at the destination**
- **Performance?**

Asynchronous Message Passing: Optimistic

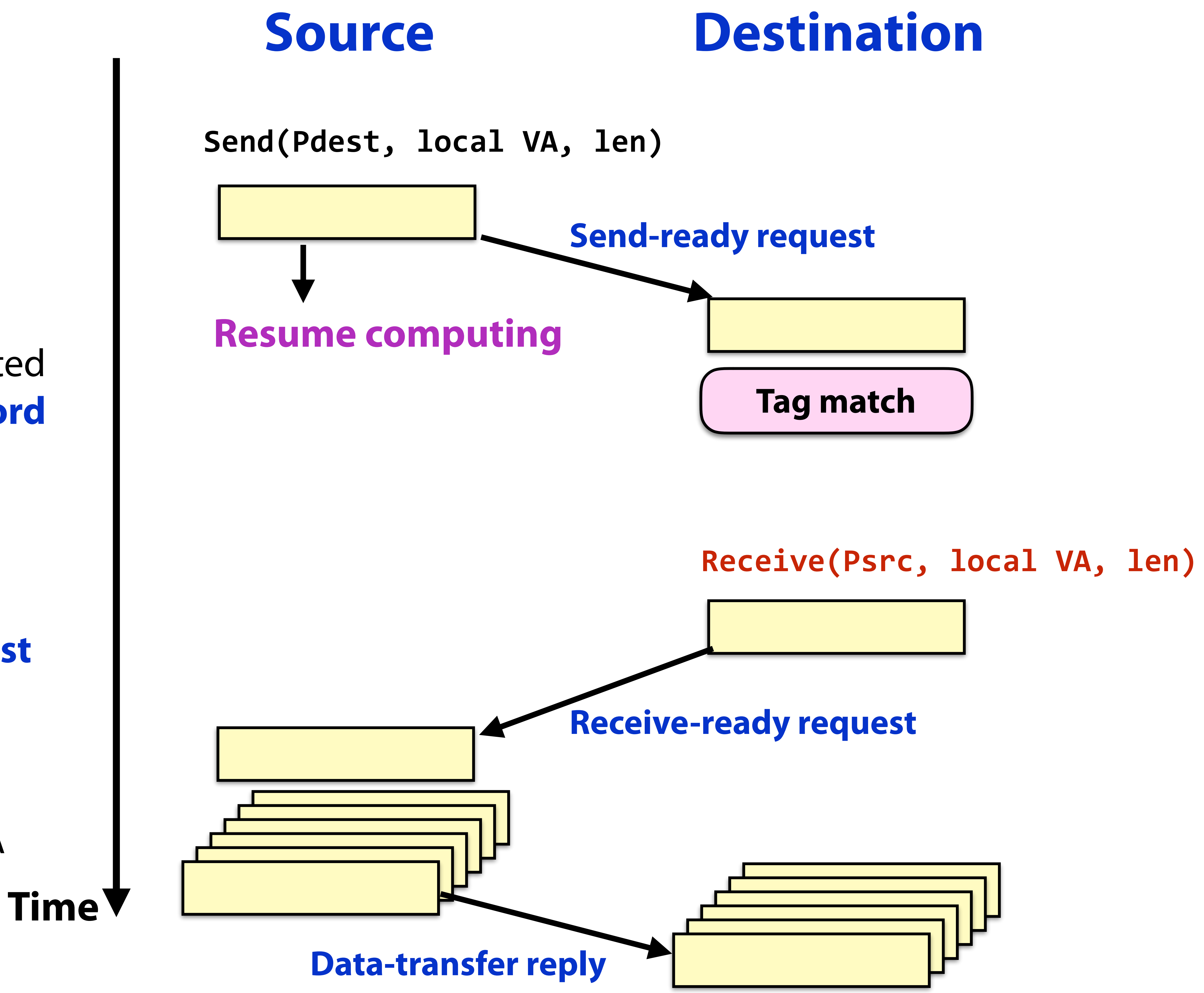
(1) Initiate send
(2) Address translation
(3) Local/remote check
(4) **Send data**

(5) Remote check for posted receive; on fail, **allocate data buffer**



- **Good news:**
  - **source does not stall waiting for the destination to receive**
- **Bad news:**
  - **storage is required within the message layer (?)**

Asynchronous Message Passing: Conservative



(1) Initiate send
(2) Address translation
(3) Local/remote check
(4) Send-ready request

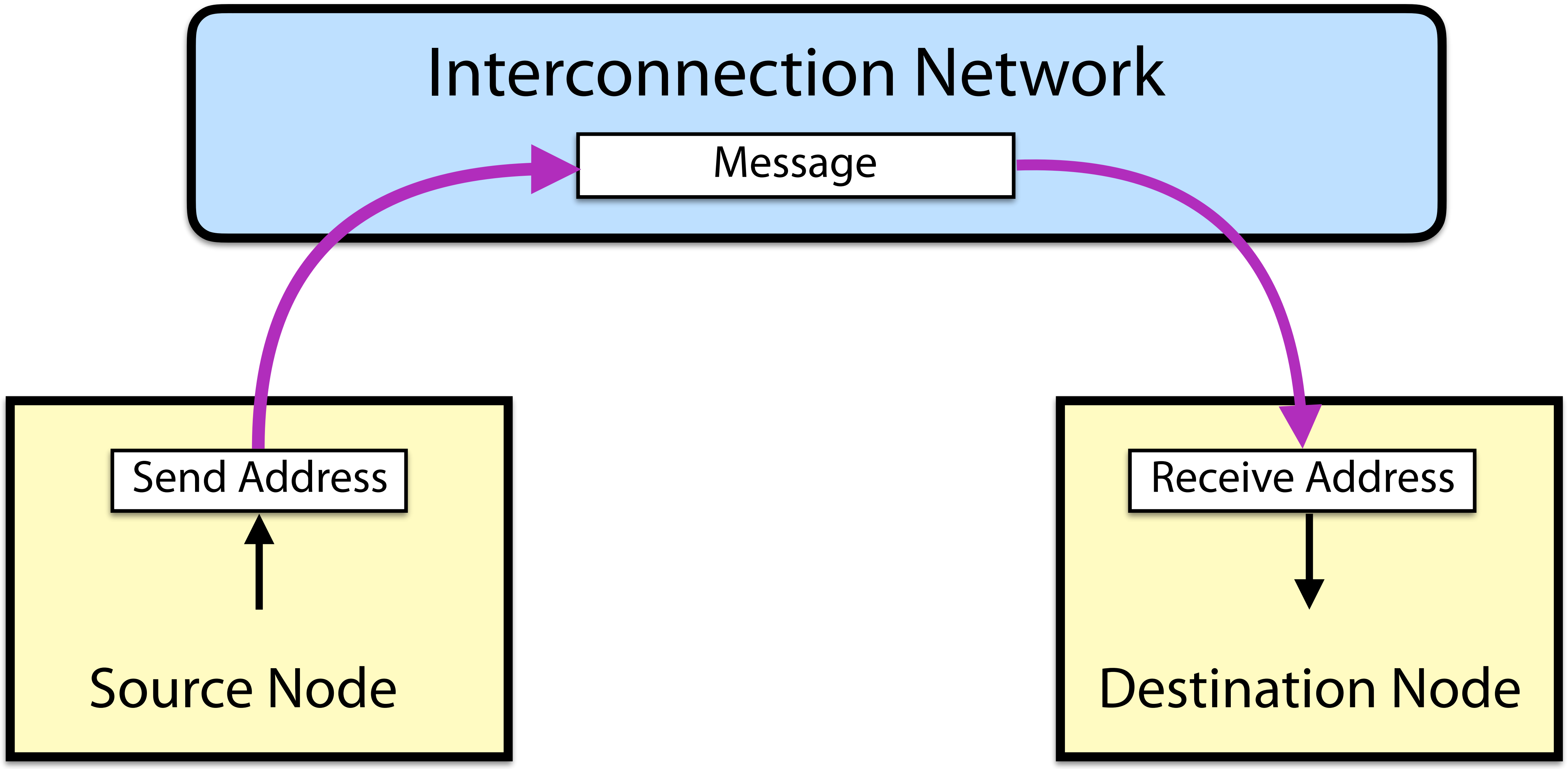
(5) Remote check for posted receive (assume fail); **record send-ready**

(6) Receive-ready request

(7) Bulk data reply
Source VA —> Dest VA

- **Where is the buffering?**
- **Contention control? Receiver-initiated protocol?**
- **What about short messages?**

Key Features of Message Passing Abstraction



- Source knows send address, destination knows receive address
  - after handshake they both know both
- Arbitrary storage "outside of the local address spaces"
  - may post many sends before any receives
- Fundamentally a 3-phase transaction

Credit-Based Async Message Passing

- **Motivation:**
  - **Optimistic** is good for short messages (lower latency), BUT
  - **Conservative** is safer in general (avoid buffer overflow)
- **Basic Idea (A Hybrid Approach):**
  - **pre-allocate limited amount of space** ("**credit**") per sender
  - if sender knows it has **sufficient credit** at a **receiver**:
    - it can go ahead and send the message **optimistically**
  - otherwise, send the message **conservatively**
- **Tracking credit limit:**
  - decreased upon send; increases piggybacked with msgs

Challenge: Avoiding Fetch Deadlock

- Must continue accepting messages, even when cannot source msgs
  - what if incoming transaction is a request?
    - each may generate a response, which cannot be sent!
    - what happens when internal buffering is full?

Approaches:

1. Logically independent request/reply networks
   - physical networks
   - virtual channels with separate input/output queues
2. Bound requests and reserve input buffer space
   - K(P-1) requests + K responses per node
   - service discipline to avoid fetch deadlock?
3. NACK on input buffer full
   - NACK delivery?

Implementation Challenges: Big Picture

- **One-way transfer** of information
- **No global knowledge**, nor global control
  - barriers, scans, reduce, global-OR give fuzzy global state
- **Very large number of concurrent transactions**
- Management of **input buffer resources**
  - many sources can issue a request and over-commit destination before any see the effect
- **Latency is large enough that you are tempted to "take risks"**
  - e.g., optimistic protocols; large transfers; dynamic allocation