15-441 Spring 06
Project 2: Network Layer

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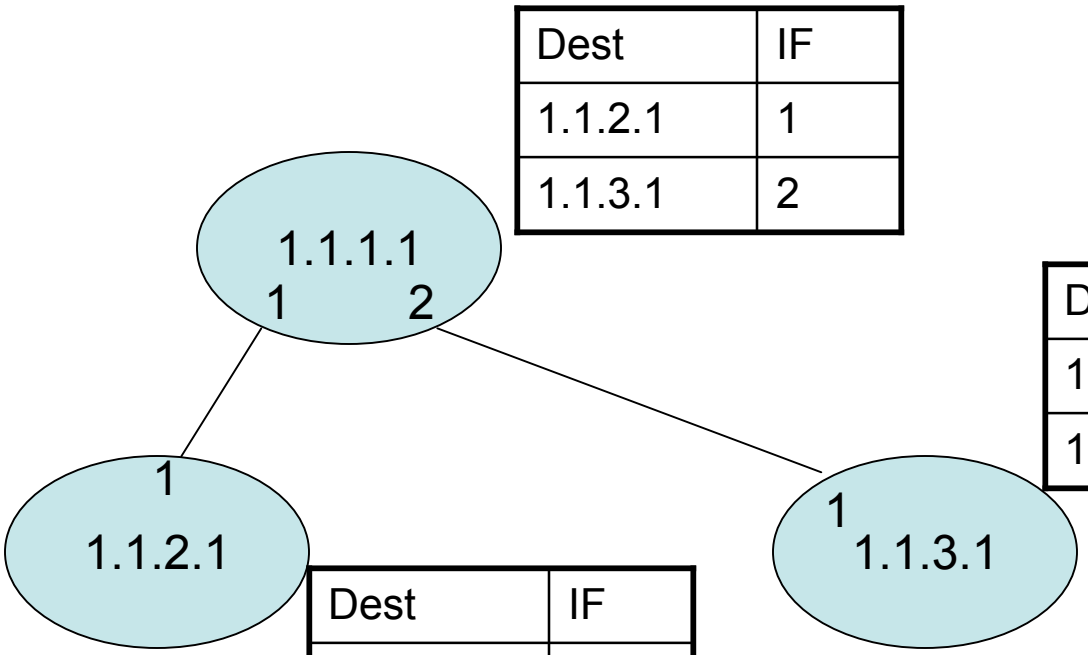
Network Layer

- Gets data from host A to host B
  - Global addressing uniquely identifies A and B
  - Data finds its way to host B, directly or indirectly
  - Don’t care how how they are connected, as long as they are.
- Where is host B, and how to get there?

Forwarding

- Finds host B by looking up in a forwarding table.



Dest	IF
1.1.2.1	1
1.1.3.1	2

Dest	IF
1.1.1.1	1
1.1.2.1	1

Dest	IF
1.1.1.1	1
1.1.3.1	1

Who makes these forwarding tables?

Routing

- Finds the paths to host B
- Fills in forwarding tables with the “best” path
- How?
  - Static
    - Manually set it (part 1)
  - Dynamic
    - Use a routing algorithm (part 2)

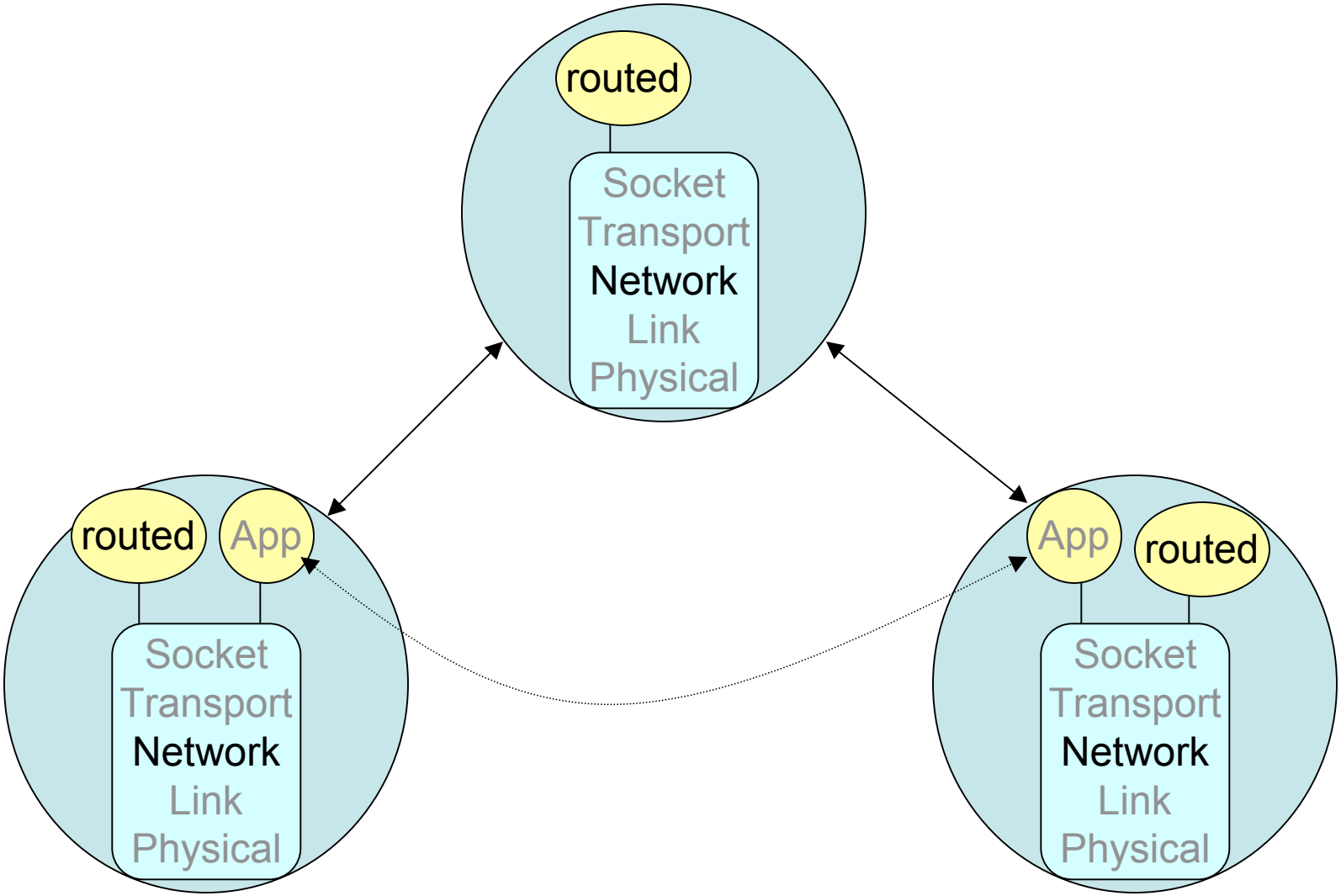
Your Mission

- Implement the network layer for a simulated operating system kernel
  - IPv4 (RFC 791)
  - Relay bytes between transport and physical layers
  - Forward packets between hosts
  - Not required: fragmentation and reassembly
- Implement a simple routing daemon
  - Using OSPF protocol

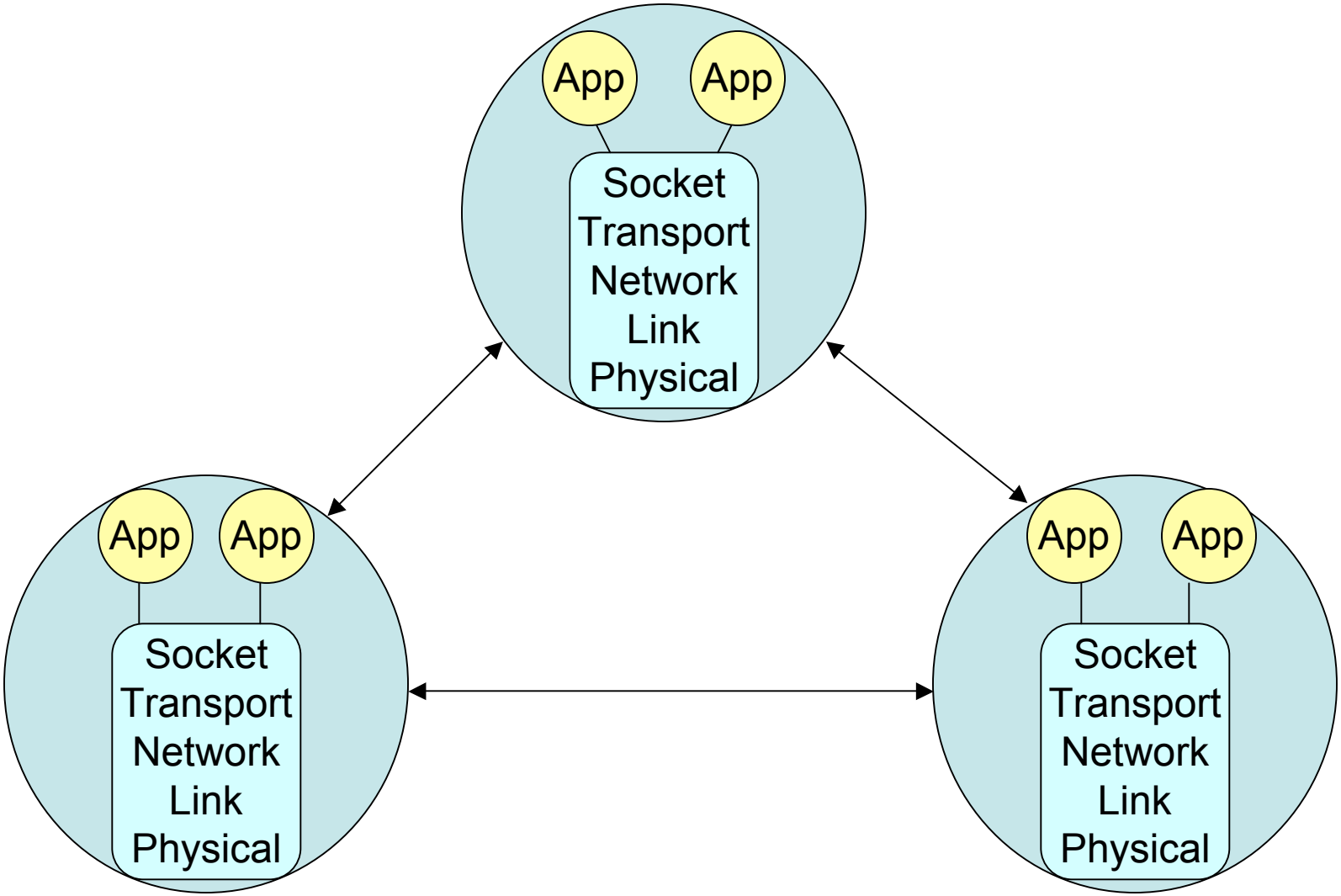
IPv4

- You must handle
  - Checksum
  - Header length
  - Packet length
  - Source and destination address
  - Protocol number
  - TTL
  - IP version number
- Your implementation need not handle
  - Fragmentation
  - Options
  - Multicast/broadcast
  - ToS

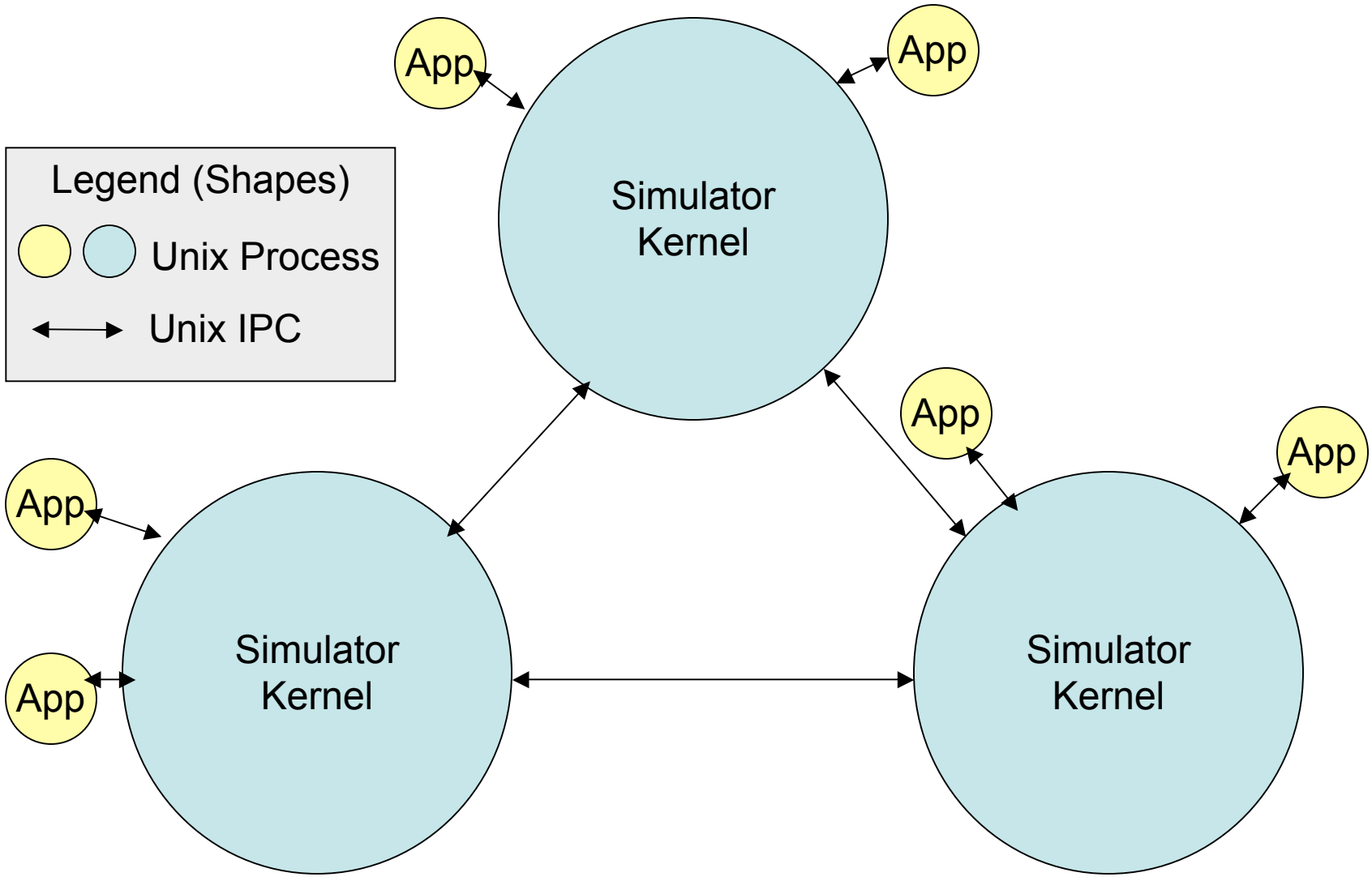
When You Are All Done



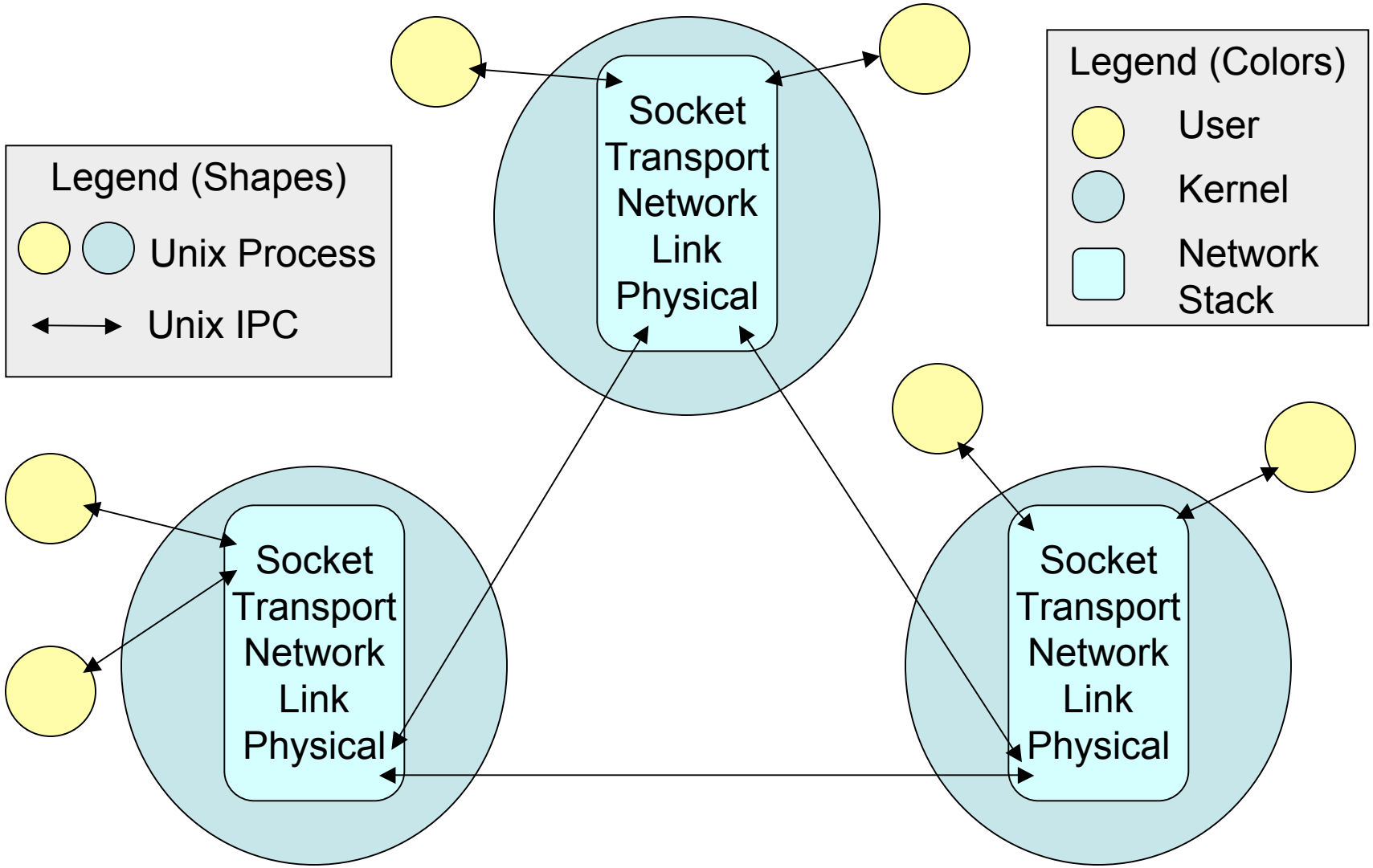
Simulator: Logical View



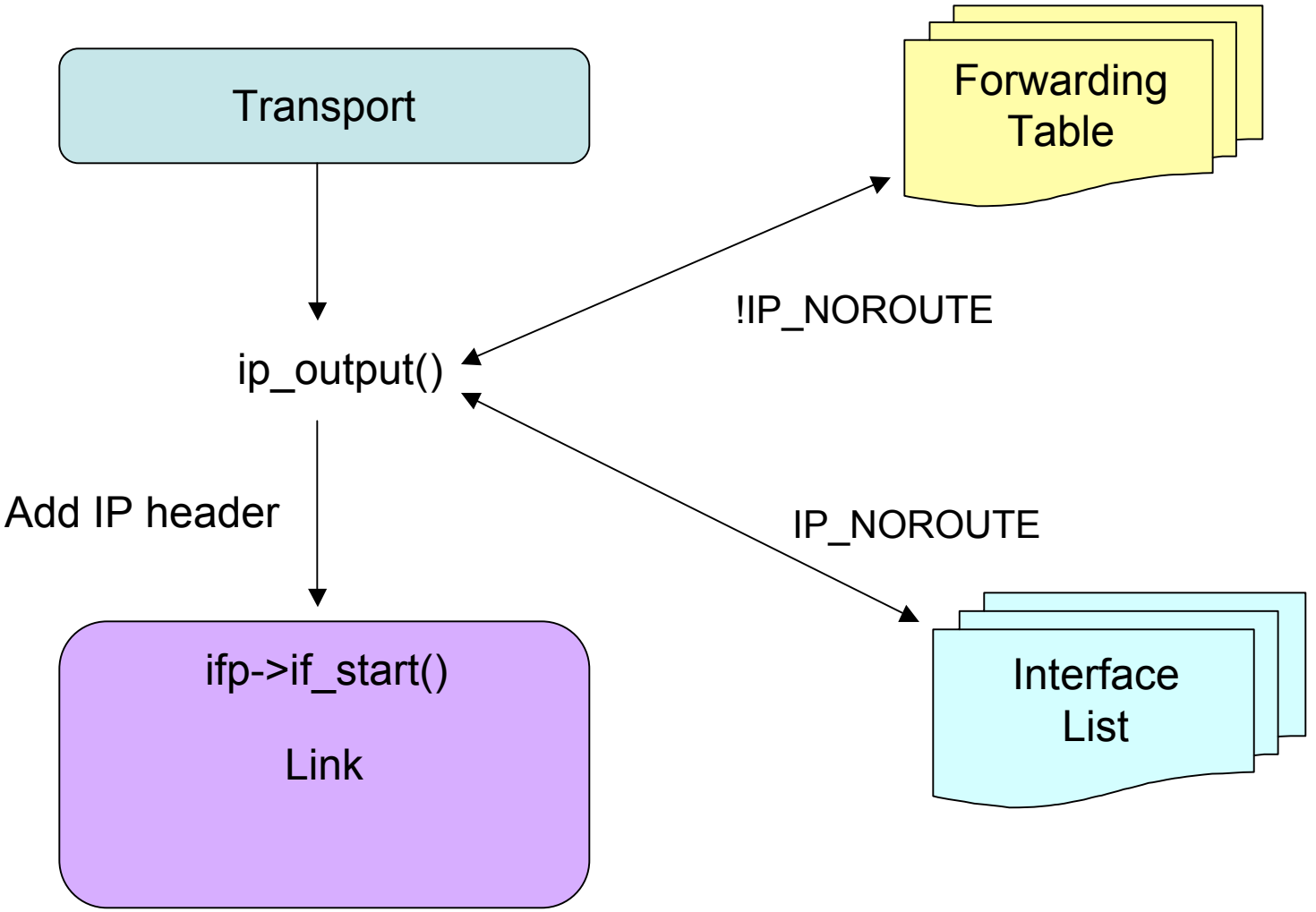
Simulator: Implementation



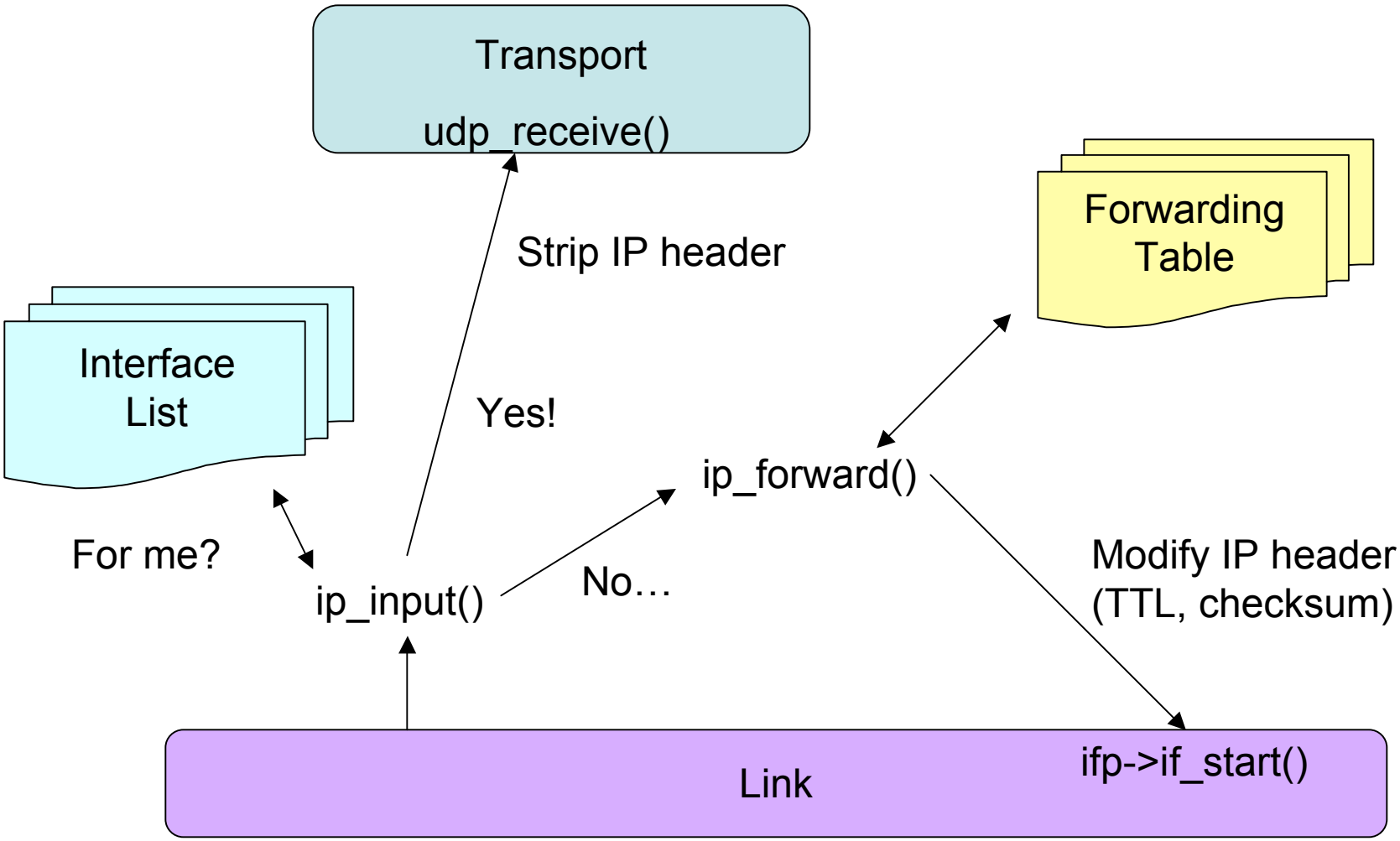
Simulator: Full Picture



Sending a Packet



Receiving a Packet

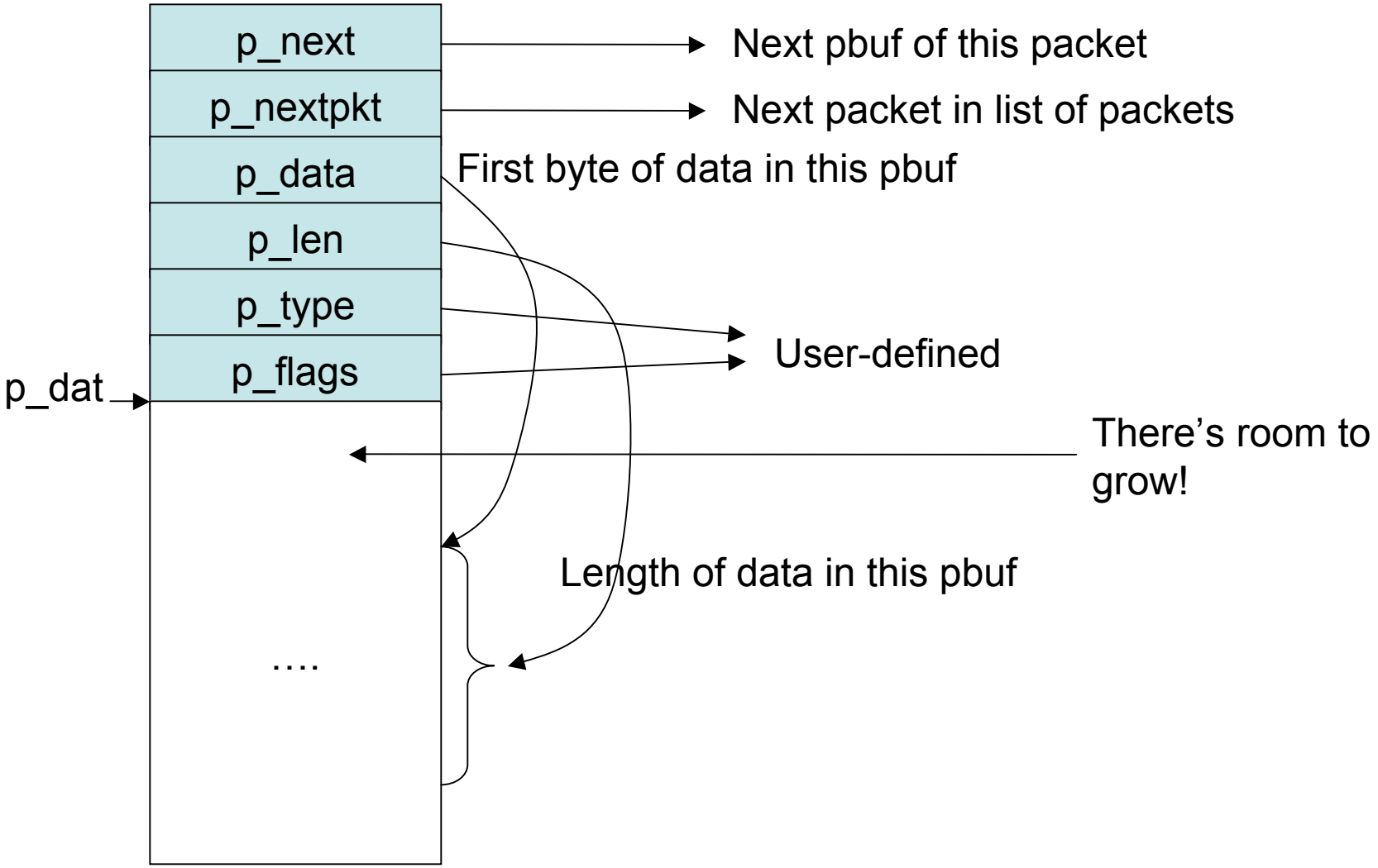


pbuf

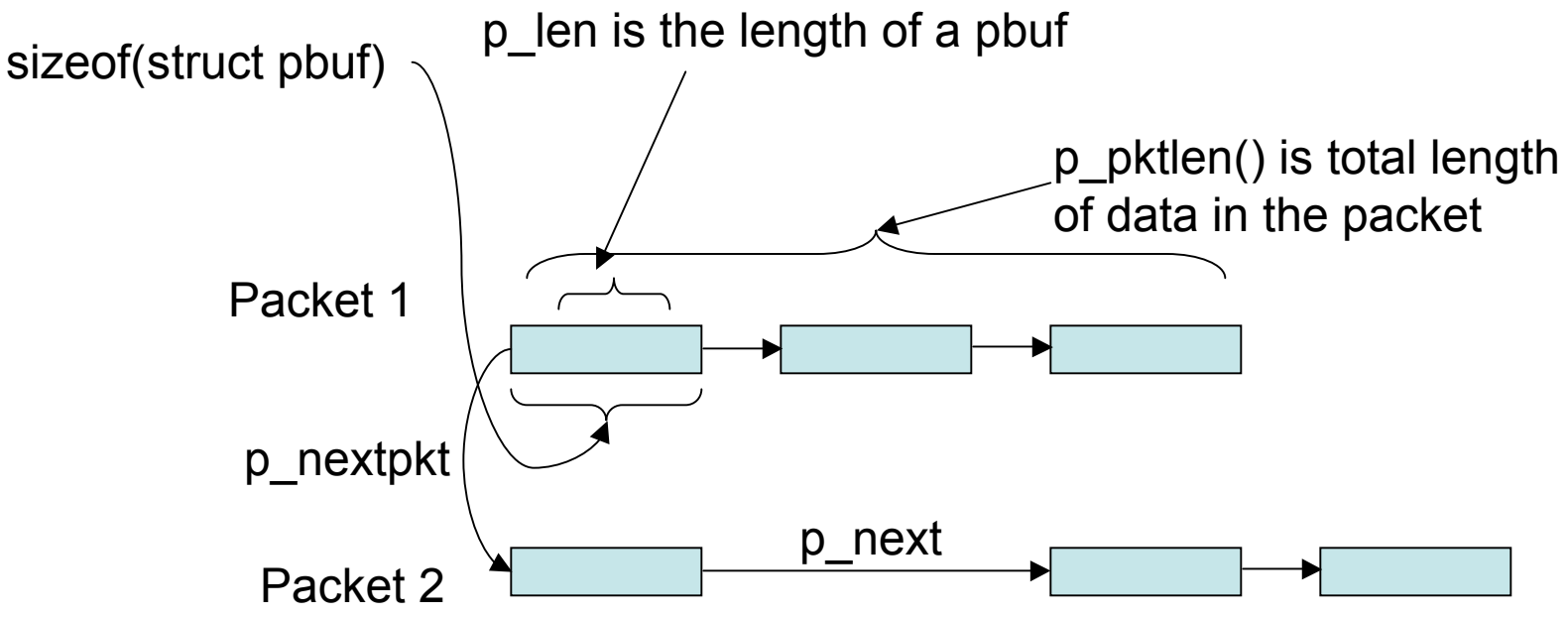
- Linked list of fixed-size (512 byte) buffers

- Why?
  - Dynamic, variable-sized memory allocation is expensive
    - Takes time, function of size of heap
    - Wastes space due to fragmentation

Inside a pbuf



pbuf Chain


sizeof(struct pbuf)
p_len is the length of a pbuf
p_pktlen() is total length
of data in the packet
Packet 1
p_nextpkt
p_next
Packet 2

IP Interface

- When ip_input() is called…
  - p_data points to beginning of IP header
  - Strip off IP header before passing onto transport layer
- When ip_output() is called…
  - p_data points be beginning of IP payload
  - Prepend an IP header before handing to link layer
  - Can assume there's enough room to prepend a IP header
    - Should not need to allocate more pbufs
- Helper functions in pbuf.h
  - p_prepend, p_strip

Connecting to the Simulator

- `#include <project2/include/Socket.h>`
- Use Socket-API functions with first letter capitalized
  - `Socket(), Bind(), Connect()` …
- Make sure to Close()
  - Simulator isn't an operating system, it doesn't clean up after you

Testing Your Network Layer

- Use `fdconfig` to set up static routes
- Try UDP applications
  - `unreliable-server`, `unreliable-client`
  - Your P1 TFTP server (single client)

Simulator Internals

- Multithreaded implementation
  - System call interface
    - User processes must register with simulator
    - One thread to handle registration requests
    - One thread per process to handle system calls
  - Network devices
    - One thread per network device
    - Wakes up when packet arrives
- What does this mean for you?
  - Your code will be executed by multiple threads..
  - Your code must be re-entrant!

Concurrency Reminder

- What you think

```
ticket = next_ticket++; /* 0 ⇒ 1 */
```

- What really happens (in general)

```
ticket = temp = next_ticket; /* 0 */
++temp; /* invisible to other threads */
next_ticket = temp; /* 1 is visible */
```

Murphy's Law (Of Threading)

- The world may *arbitrarily interleave* execution
  - Multiprocessor
    - N threads executing instructions *at the same time*
    - Of course effects are interleaved!
  - Uniprocessor
    - Only one thread running at a time...
    - But N threads runnable, timer counting down toward zero...
- The world will choose the most painful interleaving
  - “Once chance in a million” happens every minute

Your Hope

T0		T1	
`tkt = tmp =n_tkt;`	0		
`++tmp;`	1		
`n_tkt = tmp;`	1		
		`tkt = tmp =n_tkt;`	1
		`++tmp;`	2
		`n_tkt = tmp`	2
Final Value	1		2

Your Bad Luck

T0		T1	
`tkt = tmp =n_tkt;`	0		
		`tkt = tmp =n_tkt;`	0
`++tmp;`	1		
		`++tmp;`	1
`n_tkt = tmp;`	1		
		`n_tkt = tmp`	1
Final Value	1		1

Two threads have the same “ticket” !

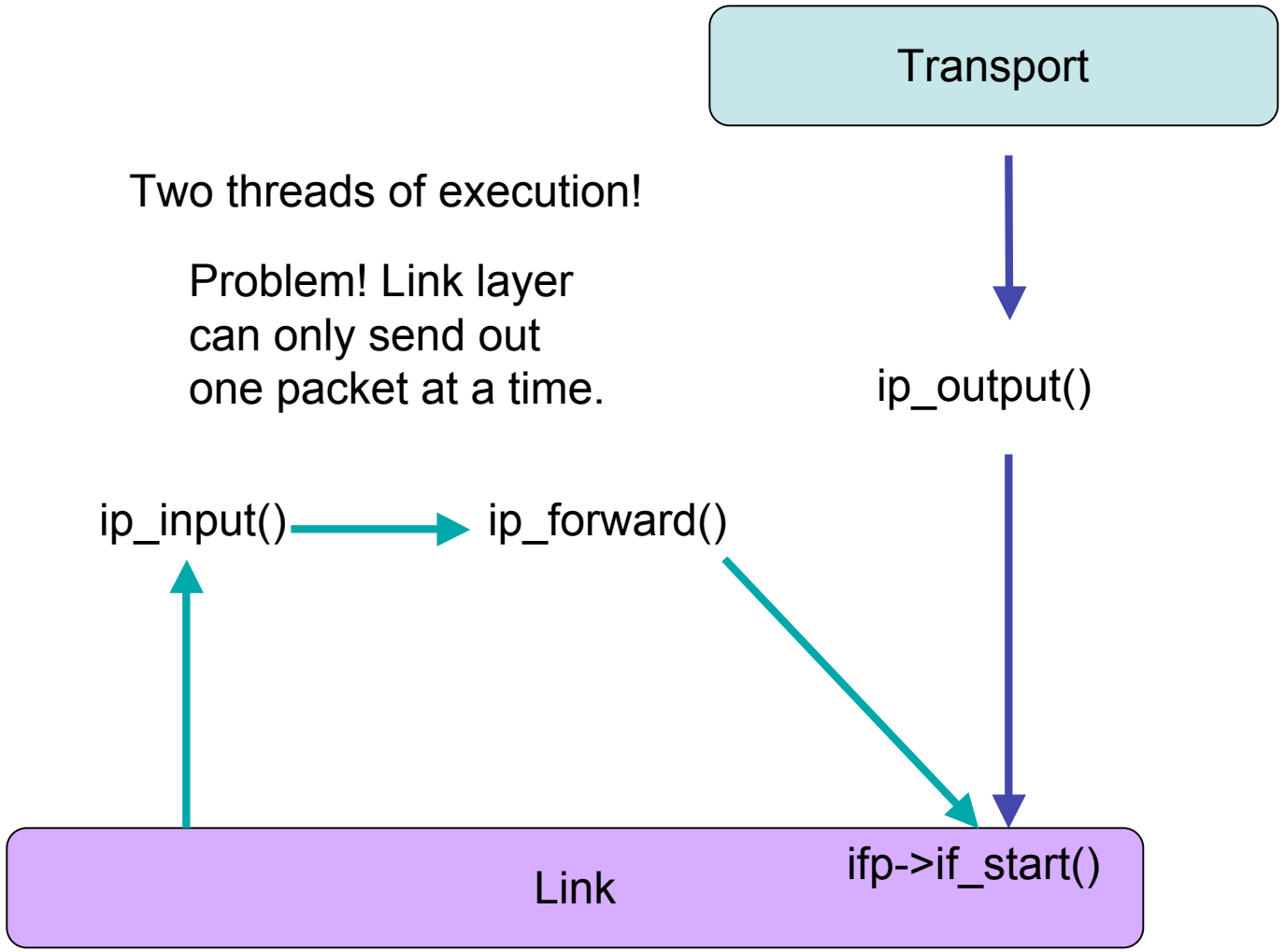
What To Do

- What you think

```
MUTEX_LOCK(m);
ticket = next_ticket++;
MUTEX_UNLOCK(m);
```

- Now no other thread's execution of the "critical section" can be interleaved with yours

IP Dataflow Revisited



One at a Time

- Only one thread can send through a particular device at a time
  - Otherwise the device will fail and cause kernel to panic.
- Need mutual exclusion
  - Use a mutex (pthread_mutex_t) for each device
  - Declared in if.h, Mutex wrappers in systm.h

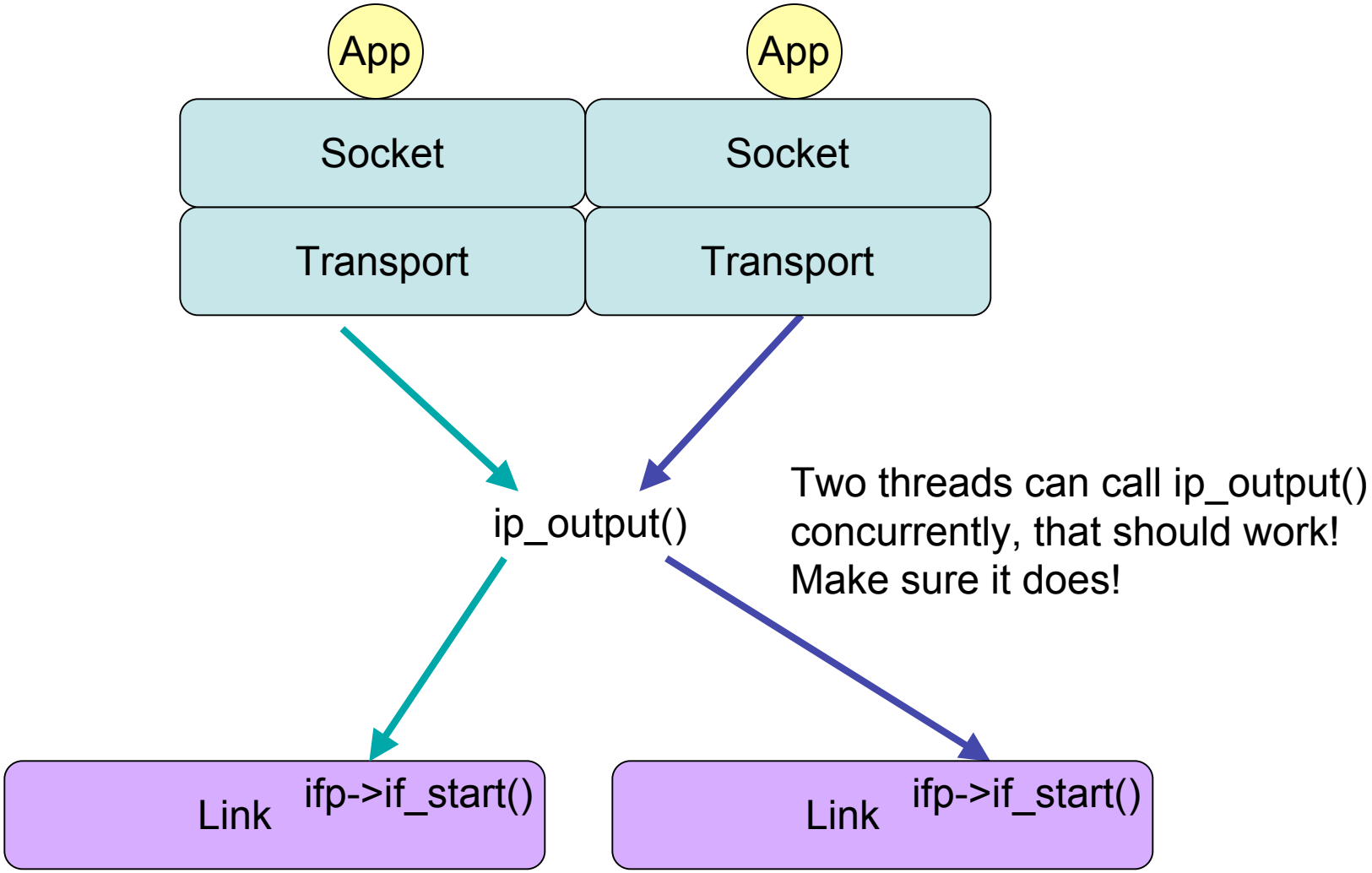
```
MUTEX_LOCK(&ifp->if_mutex);

ifp->start(ippkt);
…

MUTEX_UNLOCK(&ifp->if_mutex);
```

Critical section! Mutex ensures that only one thread can enter at a time.

IP Dataflow Revisited (again)



Many at a Time

- More than one thread could invoke an IP layer function at the same time
  - Each invocation has to be independent of one another
  - Each invocation needs to have its own state
    - Stack variables are independent, global variables are shared
  - Shared state needs to be protected

Debugging Multiple Threads

- Using `gdb`
  - `info thread` lists all running threads
  - `thread` *n* switches to a specific thread
  - `bt` to get stack trace for the current thread
  - Look for the function `thread_name` in stack trace, name of thread is in the argument
    - "link n:i to k:j" device thread for interface i on node n to interface j on node k
    - "user_pid" system call handling thread for user process pid.