# The Network Stack (2)

Lecture 6, Part 2: TCP Implementation

Prof. Robert N. M. Watson

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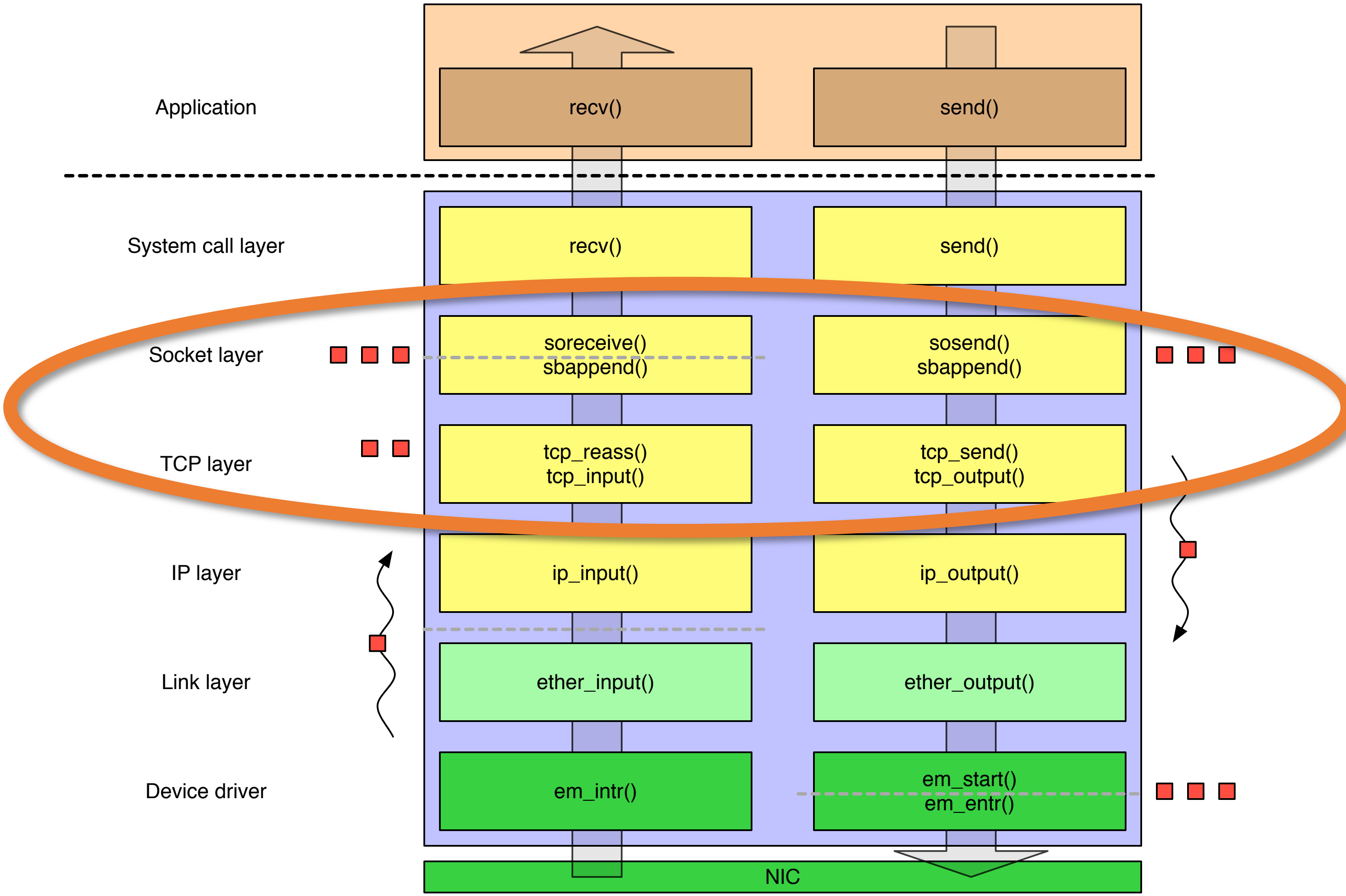
# Evolving BSD/FreeBSD TCP implementation

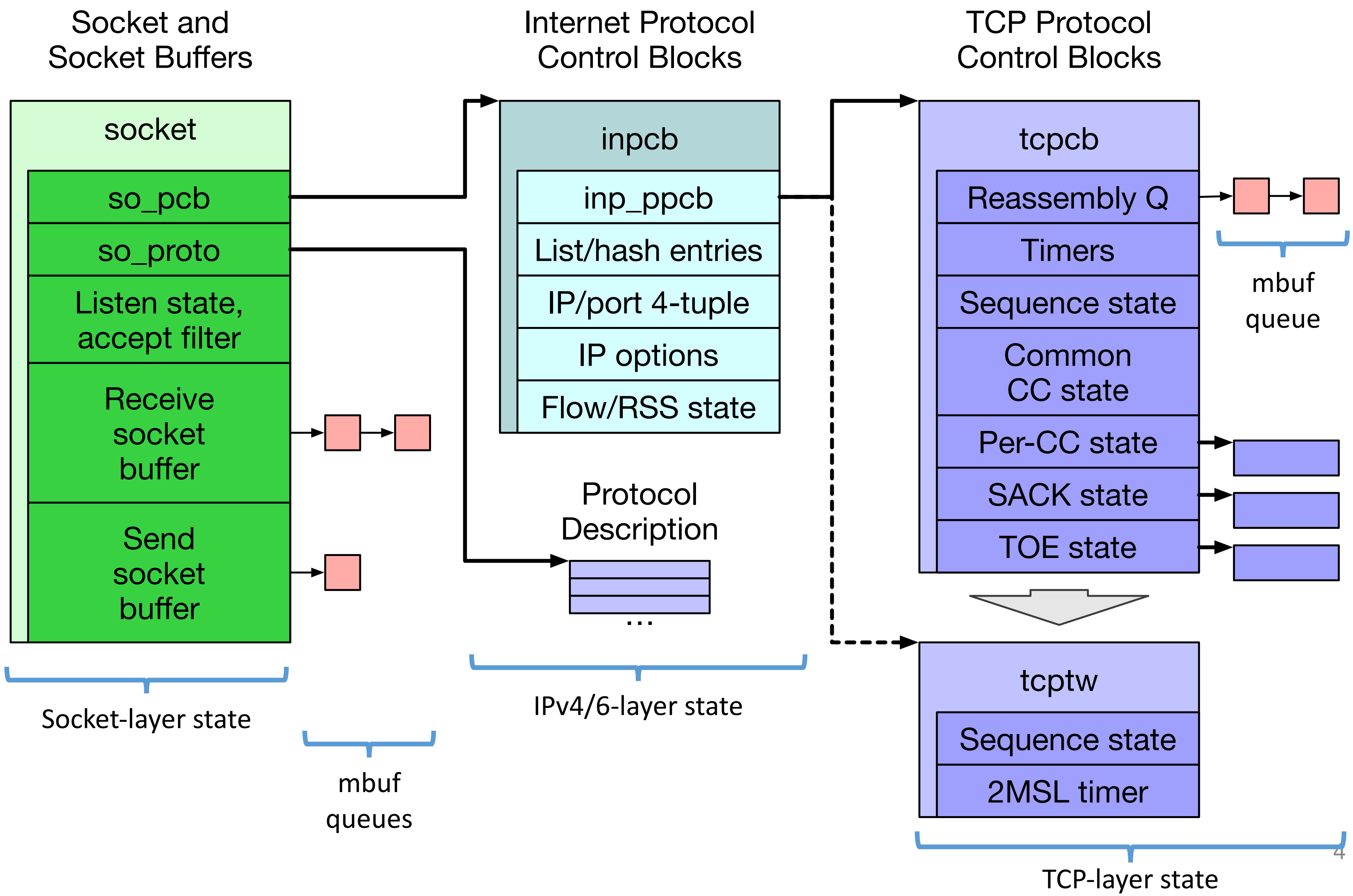
| Year | Version | Feature | |
|---|---|---|---|
| 1983 | 4.2BSD | BSD sockets, TCP/IP implementation | Initial TCP R&D |
| 1986 | 4.3BSD | VJ/Karels congestion control | |
| 1999 | FreeBSD 3.1 | `sendfile(2)` | The commercial Internet and web hosting |
| 2000 | FreeBSD 4.2 | TCP accept filters | |
| 2001 | FreeBSD 4.4 | TCP ISN randomisation | |
| 2002 | FreeBSD 4.5 | TCP SYN cache/cookies | |
| 2003 | FreeBSD 5.0-5.1 | IPv6, TCP TIMEWAIT state reduction | |
| 2004 | FreeBSD 5.2-5.3 | TCP host cache, SACK, fine-grained locking | Multicore, 10gbps, … |
| 2008 | FreeBSD 6.3 | TCP LRO, TSO | |
| 2008 | FreeBSD 7.0 | T/TCP removed, socket-buffer autosizing | |
| 2009 | FreeBSD 7.1 | Read-write locking, full TCP offload (TOE) | |
| 2009 | FreeBSD 8.0 | TCP ECN | More CC, more SMP |
| 2012 | FreeBSD 9.0 | Pluggable TCP congestion control, connection groups | |

- … changes continue to this day … BBR, RCU, pluggable TCP, KTLS, …
- Which changes have protocol-visible effects vs. only code?

# Reminder: Send/receive paths in the network stack



# Data structures – sockets, control blocks



# Denial of Service (DoS) – state minimisation

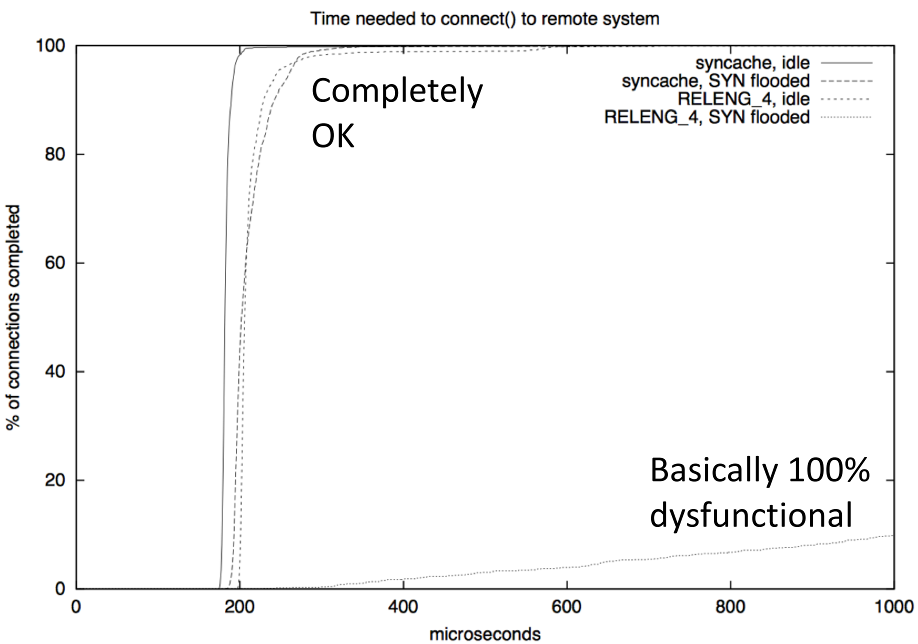
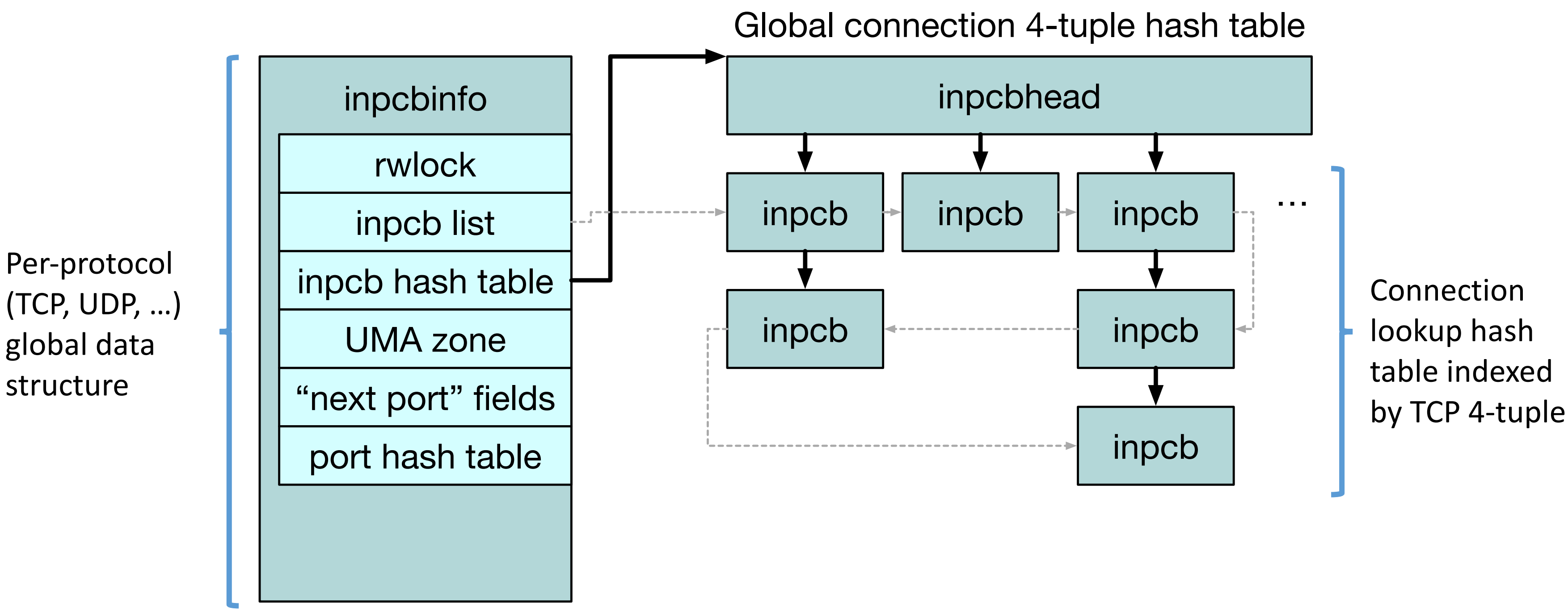



Figure 3: Time needed to connect() to remote system.

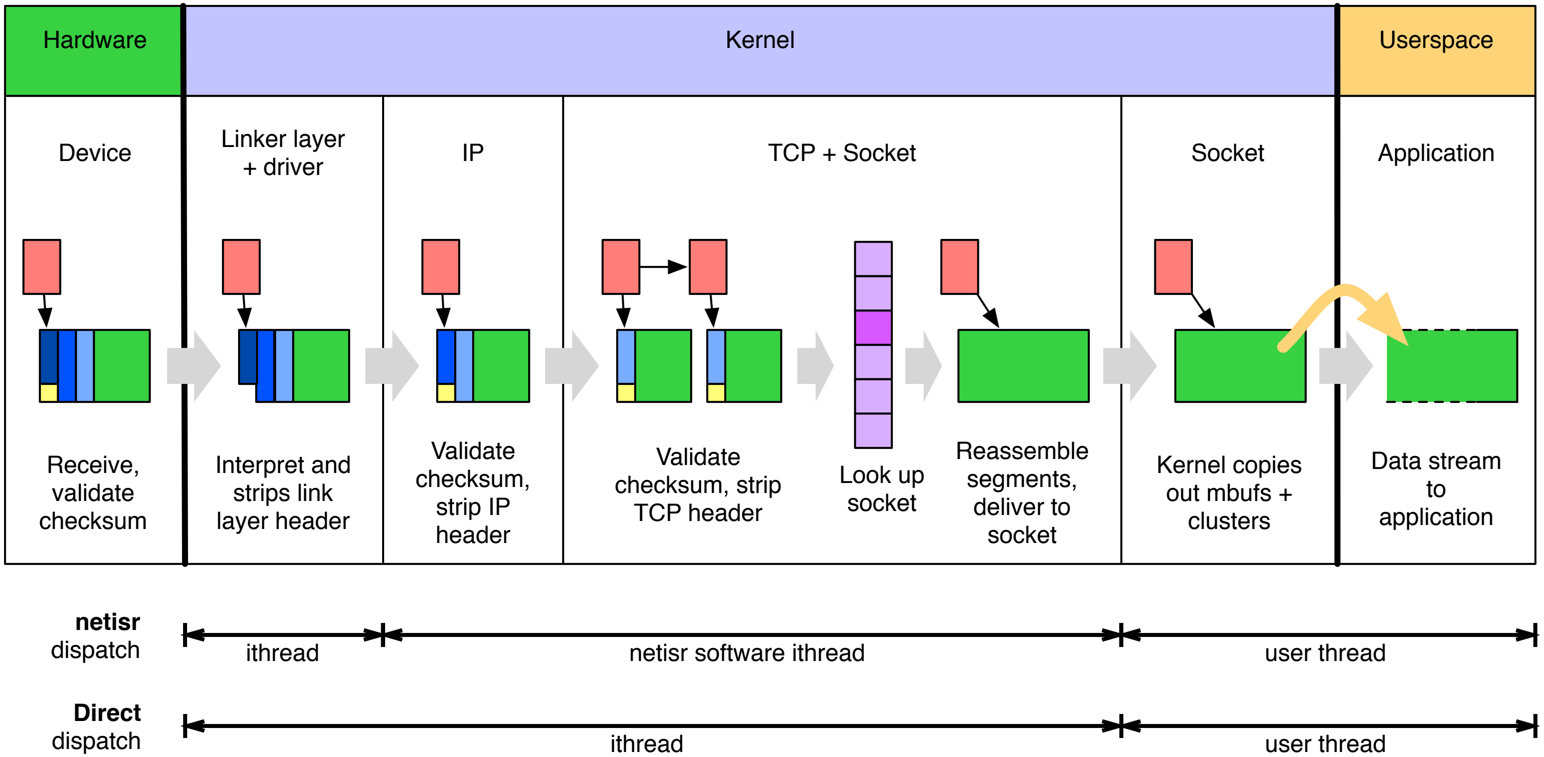
- Yahoo!, Amazon, CNN taken down by SYN floods in February 2000
- Attackers exploit automatic state allocation to overload servers
  - TCP state itself
  - Underlying routing state
  - Cost of walking data structures
- Attackers spoof SYN packets with random source addresses
  - IPv4 address use is sparse, so no RST
- D. Borman: **TCP SYN cache** – minimise state for new connections
- D. Bernstein: **SYN cookies** – eliminate state entirely – at a cost
- J. Lemon: **TCP TIMEWAIT reduction** – minimise state during long close sequences (e.g., 2MSL)
- J. Lemon: **TCP TIMEWAIT recycle** – release state early under load

# TCP connection lookup tables (original BSD)




- Global list of connections for monitoring (e.g., netstat)
- Connections are installed in a global hash table for lookup
  - NB: separate (similar) hash table for 2-tuple port-number allocations
- Tables protected by global read-write lock as reads dominate
  - New packets are more frequent than new connections

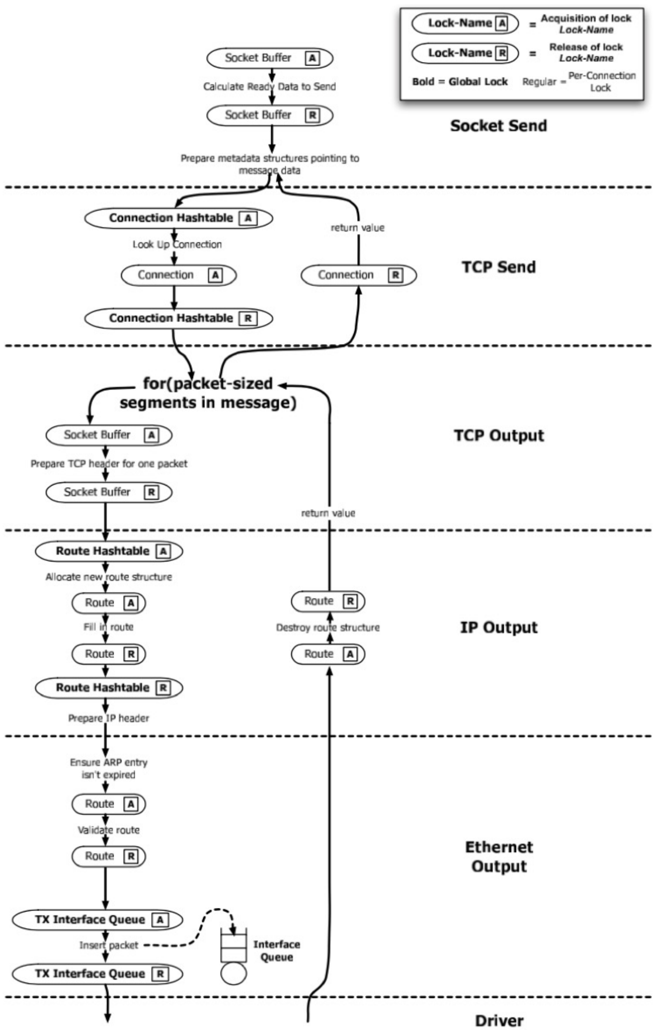
# Reminder - Work dispatch: input path




- **Deferred dispatch**: ithread → netisr thread → user thread
- **Direct dispatch**: ithread → user thread
  - Pros: reduced latency, better cache locality, drop early on overload
  - Cons: reduced parallelism and work placement opportunities

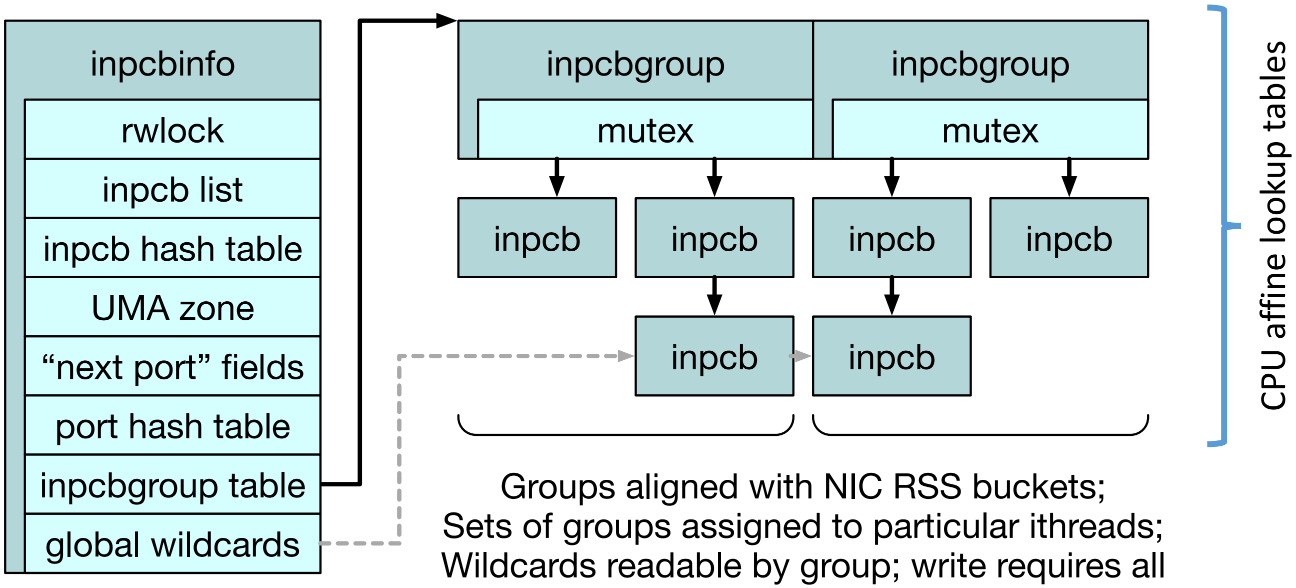
# *An Evaluation of Network Stack Parallelization Strategies in Modern Operating Systems*

Paul Willmann, Scott Rixner, and Alan L. Cox, USENIX ATC, 2006




- Network bandwidth growth > CPU frequency growth
- Locking overhead (space, contention) substantial
  - Getting 'speedup' is hard!
- Evaluate different strategies for TCP processing parallelisation
  - Message-based parallelism
  - Connection-based parallelism (threads)
  - Connection-based parallelism (locks)
- Coalescing locks over connections:
  - reduces overhead
  - increases parallelism

# Connection groups, RSS (FreeBSD)




- From FreeBSD 9.x: **Connection groups** blend MsgP and ConnP-L models
  - PCBs assigned to group based on 4-tuple hash
  - Lookup requires group lock, not global lock
  - Global lock retained for 4–tuple reservation (e.g., setup, teardown)
- Problem: have to look at TCP headers (cache lines) to place work!
  - Microsoft: NIC **Receive-Side Steering (RSS)**
  - Multi-queue NICs deliver packets to queues using hash of 4-tuple
  - Align connection groups with RSS buckets / interrupt routing
- From FreeBSD 12.x: **Read-Copy-Update (RCU)**, **Safe Memory Reclamation (SMR)** rather than RW locks protect lists
  - Do we still need complex, decentralised data structures with more powerful cores, lockless techniques …?