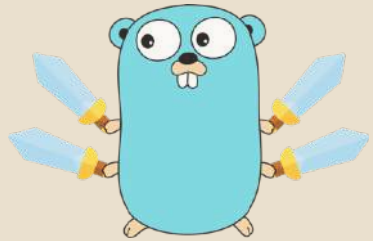
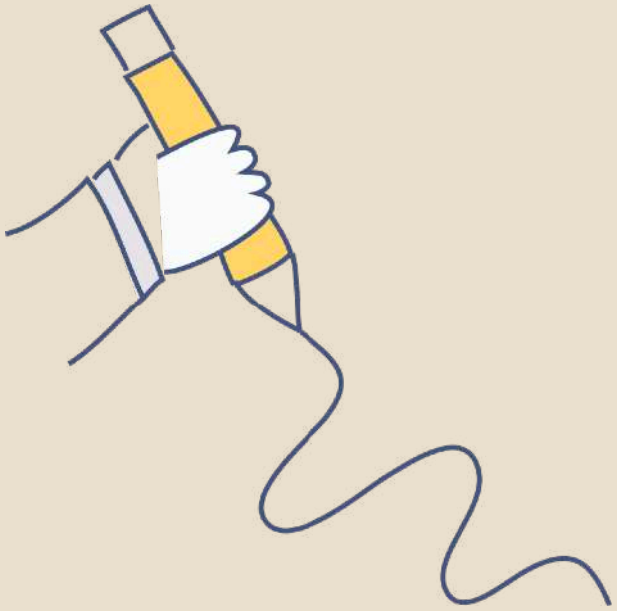
网络编程的那些事儿 v1

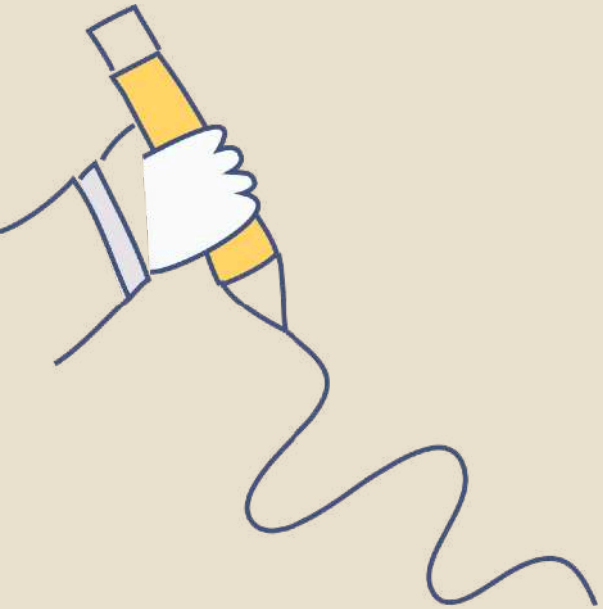
xiaorui.cc

github.com/rfyiamcool





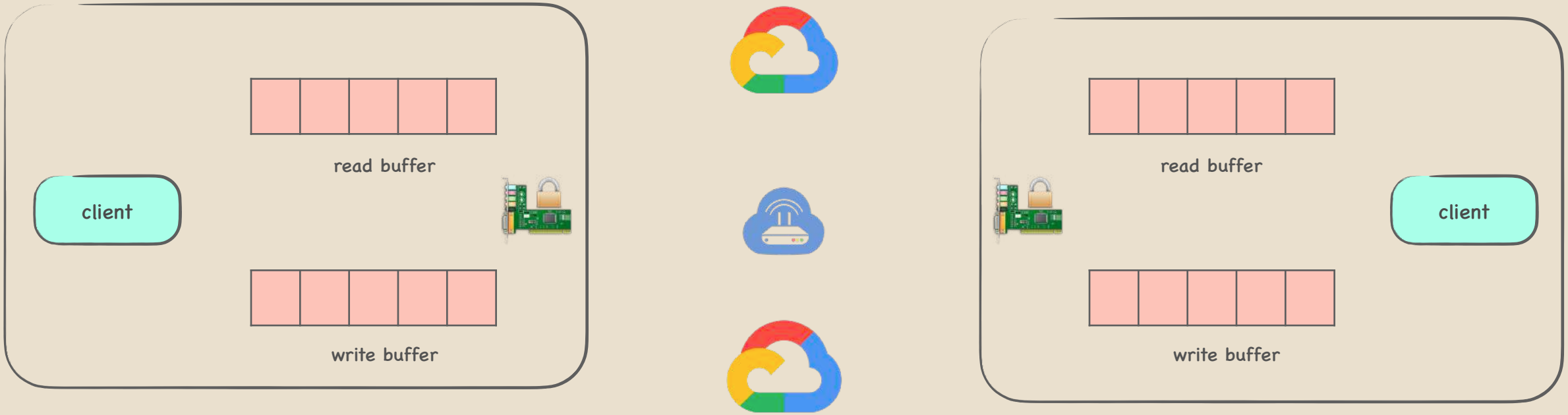
1. socket基本原理
2. io 多路复用
3. 网络模型
4. 常见问题



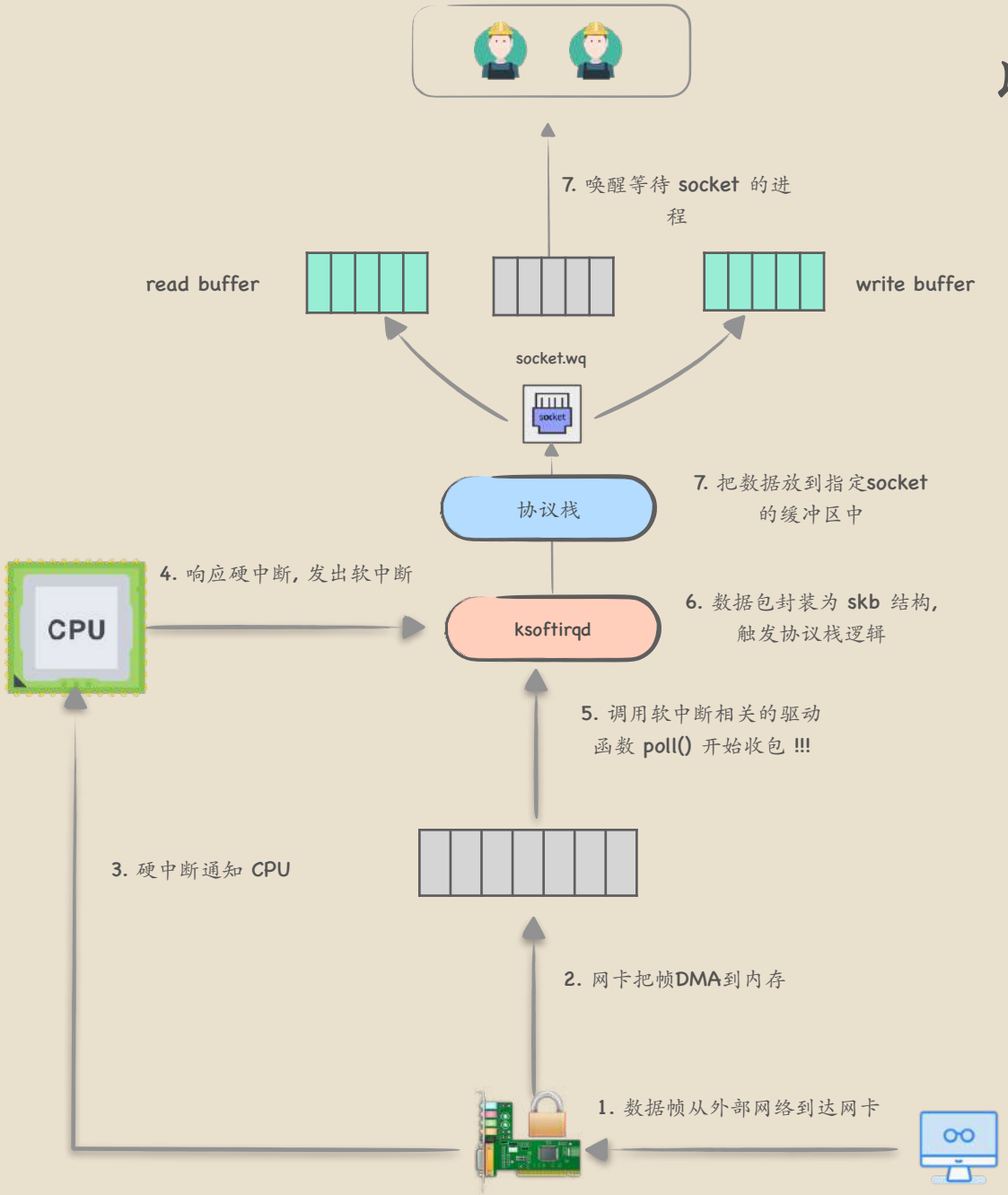
1

socket

socket

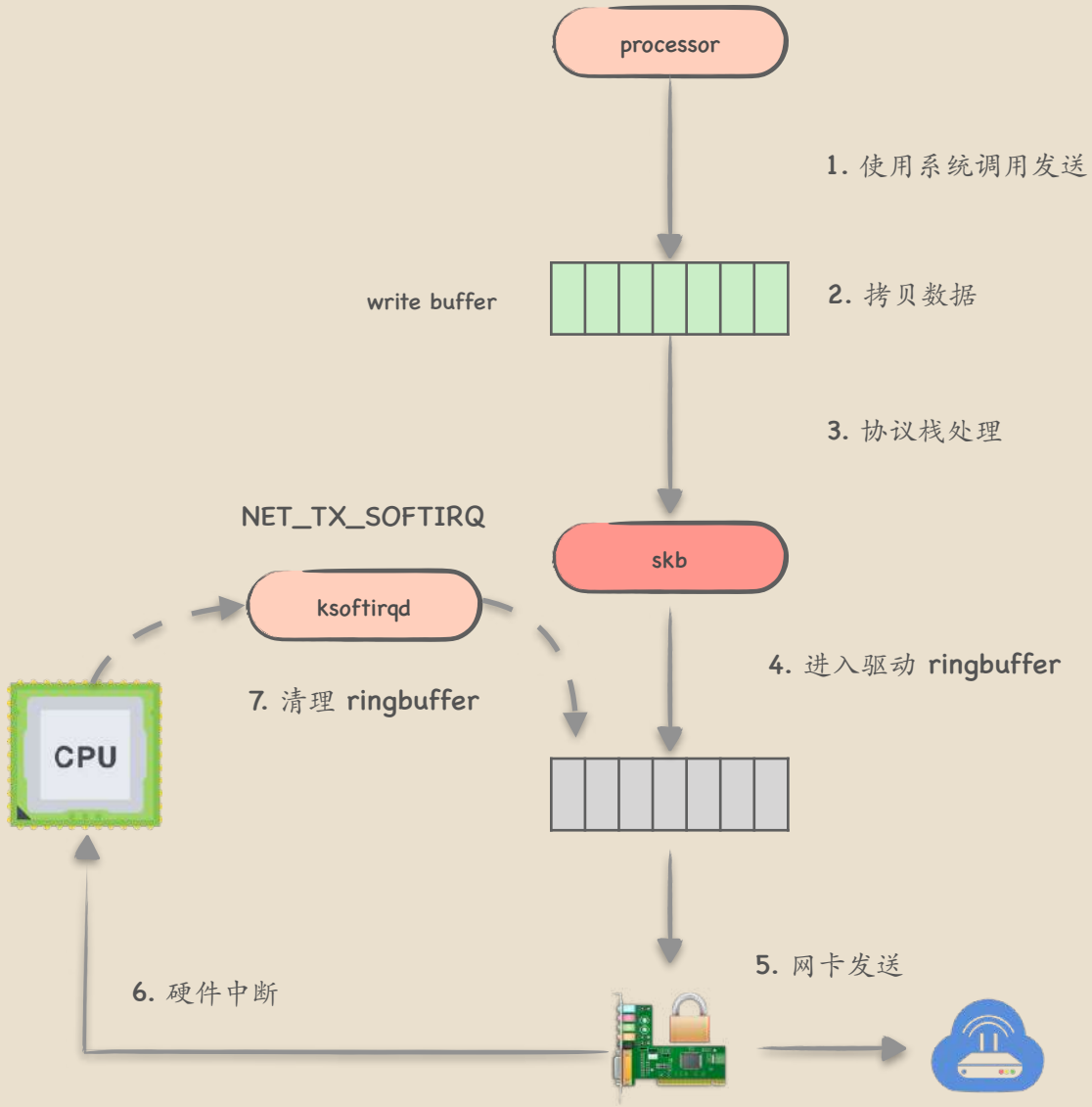

read buffer
client
write buffer
read buffer
client
write buffer

收包原理



1. 网卡将数据帧DMA到内存 RingBuffer中，然后向CPU硬中断；
2. CPU响应中断请求，调用网卡启动时注册的中断处理函数；
3. 中断处理函数几乎没干啥，就发起了软中断请求；
4. 内核线程ksoftirqd线程发现有软中断请求到来，先关闭硬中断；
5. ksoftirqd 线程开始调用驱动的 poll 函数收包；
6. 协议栈把数据包放到对应的socket的缓存队列里；
7. 调用 socket waitqueue 的回调函数链，激活等待的进程.

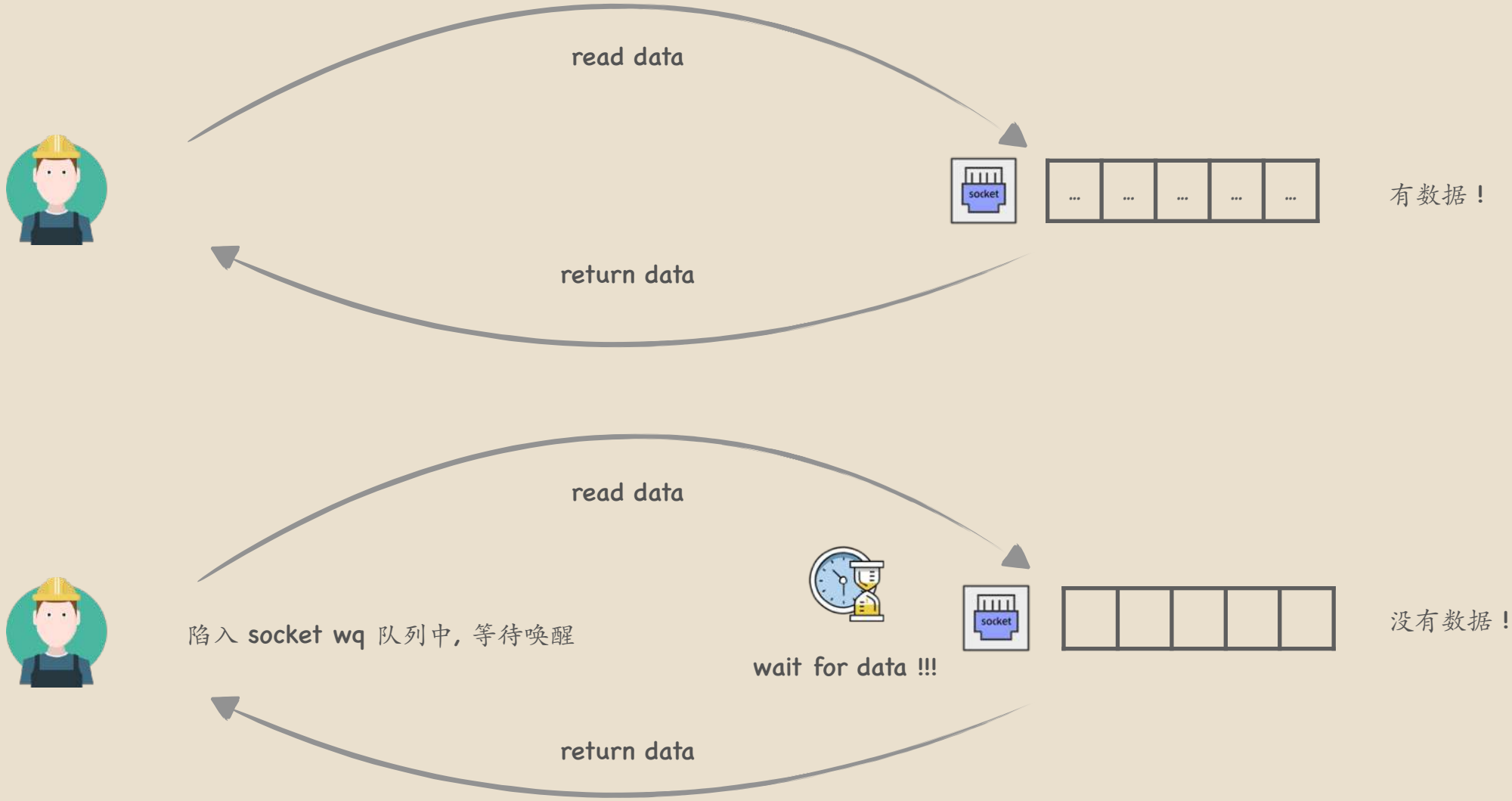
发包原理



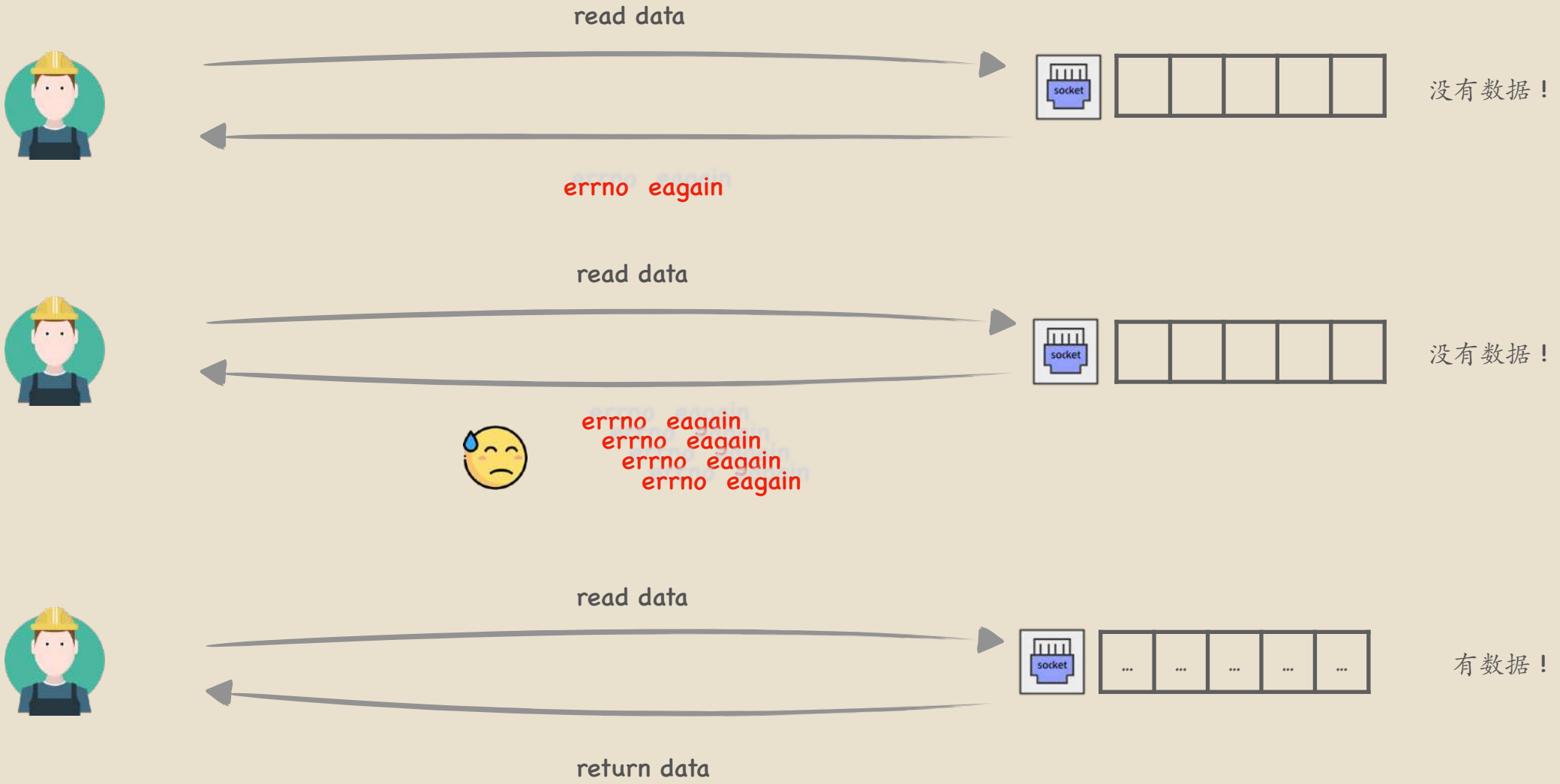
1. 使用系统调用发送
2. 拷贝数据且skb封装
3. 协议栈各种处理
4. 把数据推送到驱动ringbuffer
5. 网卡发送数据
6. 软硬中断处理
7. 清理ringbuffer

😎 write 系统调用路径特别长 !!!

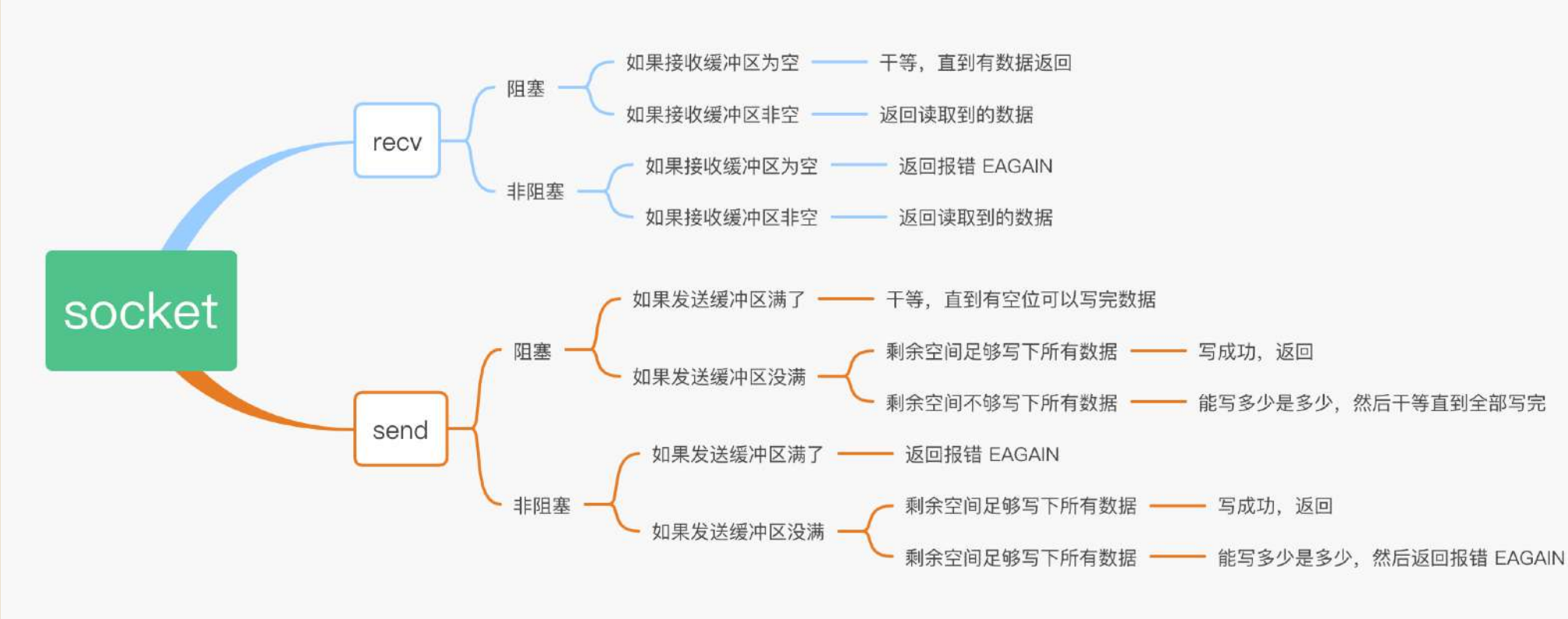
阻塞模式


read data
socket
...
...
...
...
...
有数据！
return data
read data
陷入 socket wq 队列中，等待唤醒
wait for data !!!
socket
没有数据！
return data

非阻塞模式


read data
socket
没有数据！
errno eagain
read data
socket
没有数据！
errno eagain
errno eagain
errno eagain
errno eagain
read data
socket
...
有数据！
return data

阻塞 vs 非阻塞


socket
recv
阻塞
如果接收缓冲区为空
干等，直到有数据返回
如果接收缓冲区非空
返回读取到的数据
非阻塞
如果接收缓冲区为空
返回报错 EAGAIN
如果接收缓冲区非空
返回读取到的数据
send
阻塞
如果发送缓冲区满了
干等，直到有空位可以写完数据
如果发送缓冲区没满
剩余空间足够写下所有数据
写成功，返回
剩余空间不够写下所有数据
能写多少是多少，然后干等直到全部写完
非阻塞
如果发送缓冲区满了
返回报错 EAGAIN
如果发送缓冲区没满
剩余空间足够写下所有数据
写成功，返回
剩余空间足够写下所有数据
能写多少是多少，然后返回报错 EAGAIN

两阶段

阻塞/非阻塞 IO

同步/异步 IO

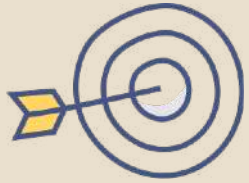
硬件网卡

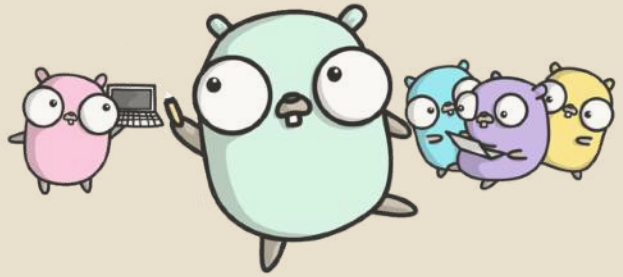
内核空间

用户空间

第一阶段

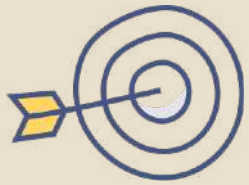
第二阶段

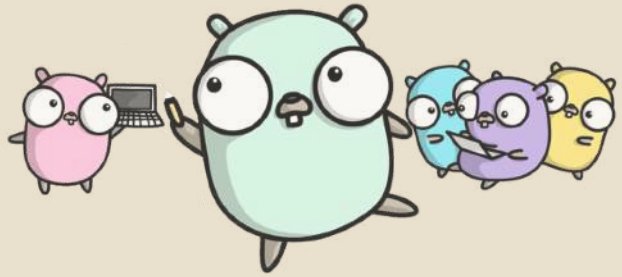




同步 vs 异步

- 同步
  - 需要主动读写数据，在读写数据的过程中还是会阻塞
- 异步
  - 无需主动读写数据，由操作系统内核完成数据的读写，等待完成通知





五种 IO 模型

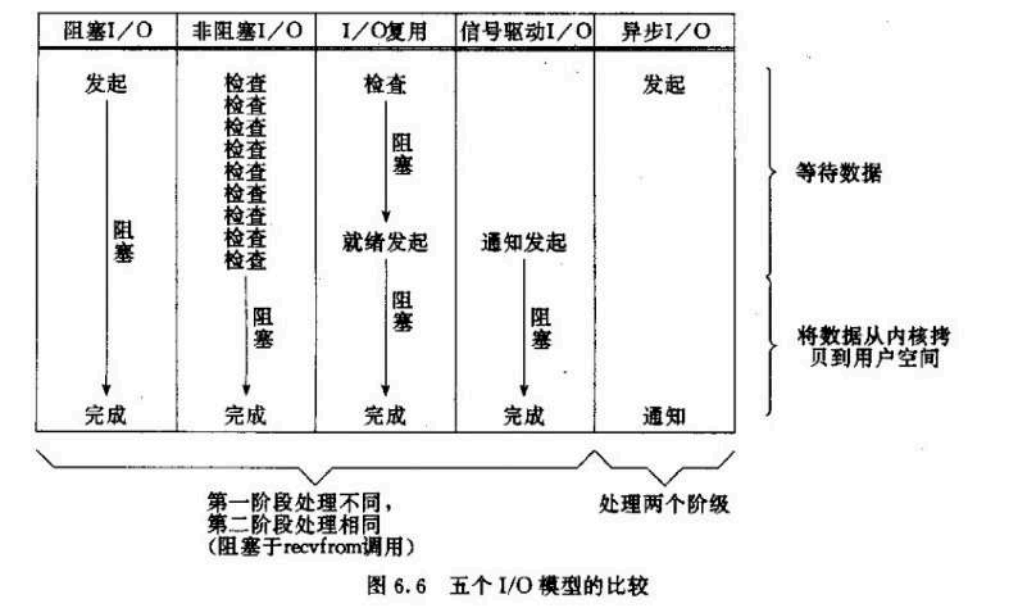
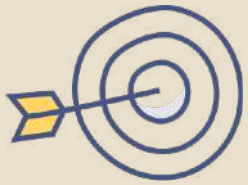


图 6.6 五个 I/O 模型的比较

- 阻塞io模型
- 非阻塞io模型
- io多路复用模型
- 信号驱动IO模型
- 异步io模型



阻塞 io 模型

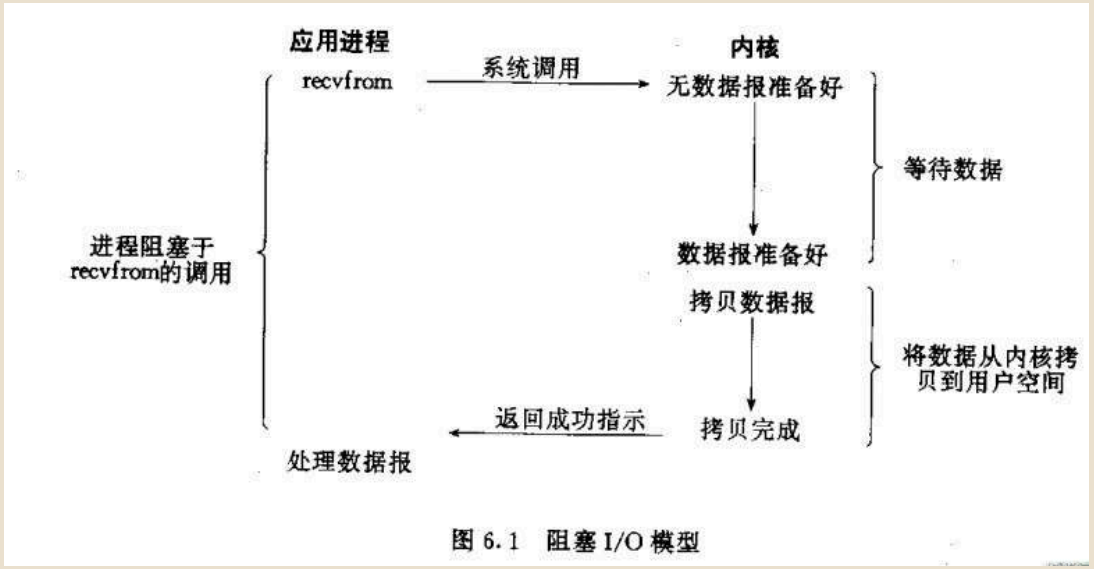
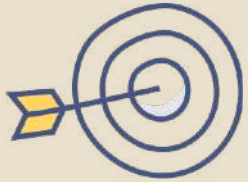


图 6.1 阻塞 I/O 模型

* 当数据不可读被挂起, 阻塞等待有数据可读.
* 当写缓冲区写满不可再写时, 阻塞挂起等待可写.
* 优点
    * 无资源时直接休眠等待
* 缺点
    * 一个线程只能监听一个fd



非阻塞 io 模型

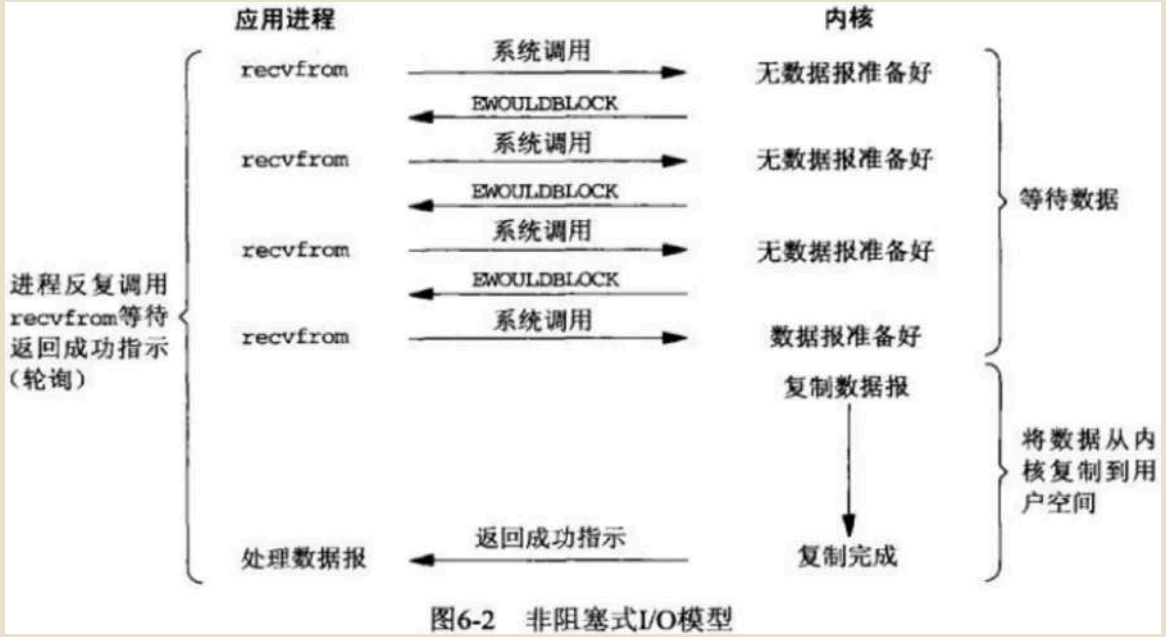


图6-2　非阻塞式I/O模型

```
int s = socket(AF_INET, SOCK_STREAM | SOCK_NONBLOCK, IPPROTO_TCP);

fcntl(sockfd, F_SETFL, fcntl(sockfd, F_GETFL, 0) | O_NONBLOCK);

ioctl(sockfd, FIONBIO, 1);  //1:非阻塞 0:阻塞
```

- socket 设为非阻塞，然后不断的短轮询，空耗 cpu 资源
- 不管是否可读，一个劲的读，无数据时返回 EAGAIN 或 EWOULDBLOCK
- 不管是否可写，一个劲的尝试写，不能写返回 EAGAIN 或 EWOULDBLOCK
- 优点？
  - 可以遍历轮询多个资源 😅
- 缺点
  - 太粗暴，空耗资源

io 多路复用模型

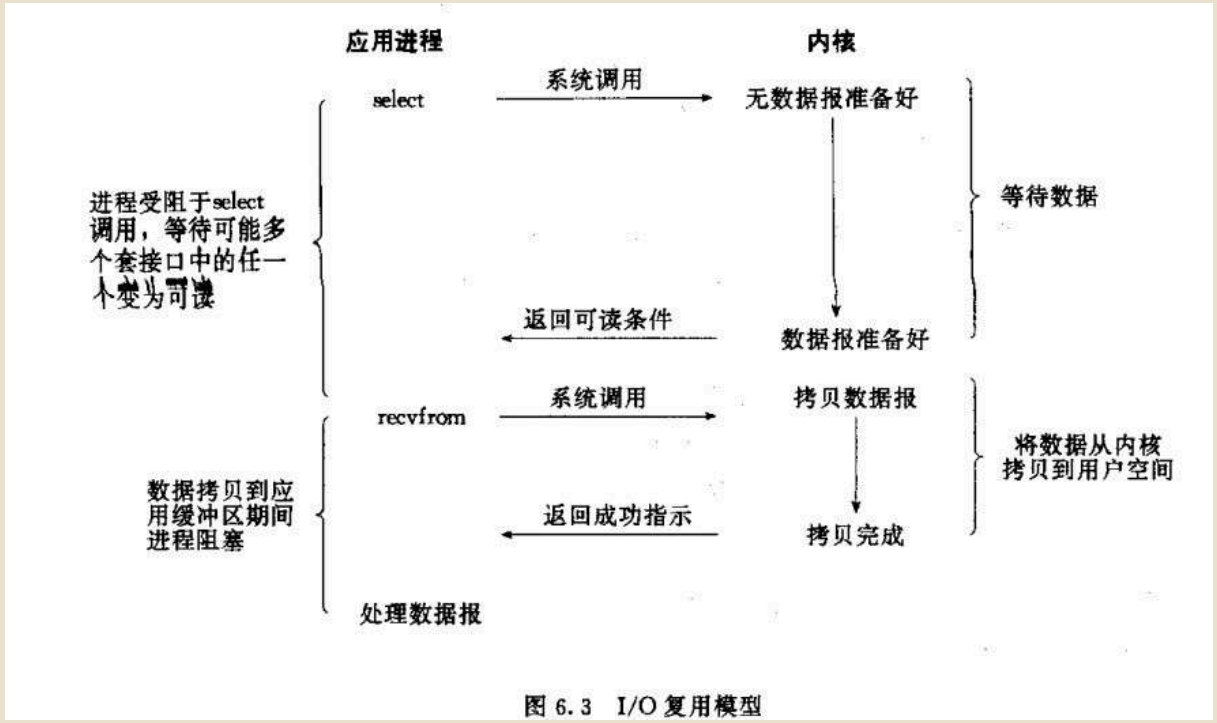
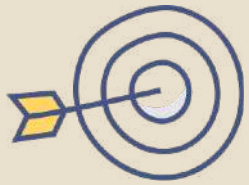


图 6.3 I/O 复用模型

* lib
  * select
  * poll
  * epoll
* 可以同时监听多个资源
* 无需轮询，有数据被唤醒，没数据则 block 等待
* 当 kernel 中数据准备好的时候，recvfrom 会将数据从 kernel拷贝到用户内存中，这个时候进程是被block了



epoll 为 同步非阻塞 模式

信号驱动io模型

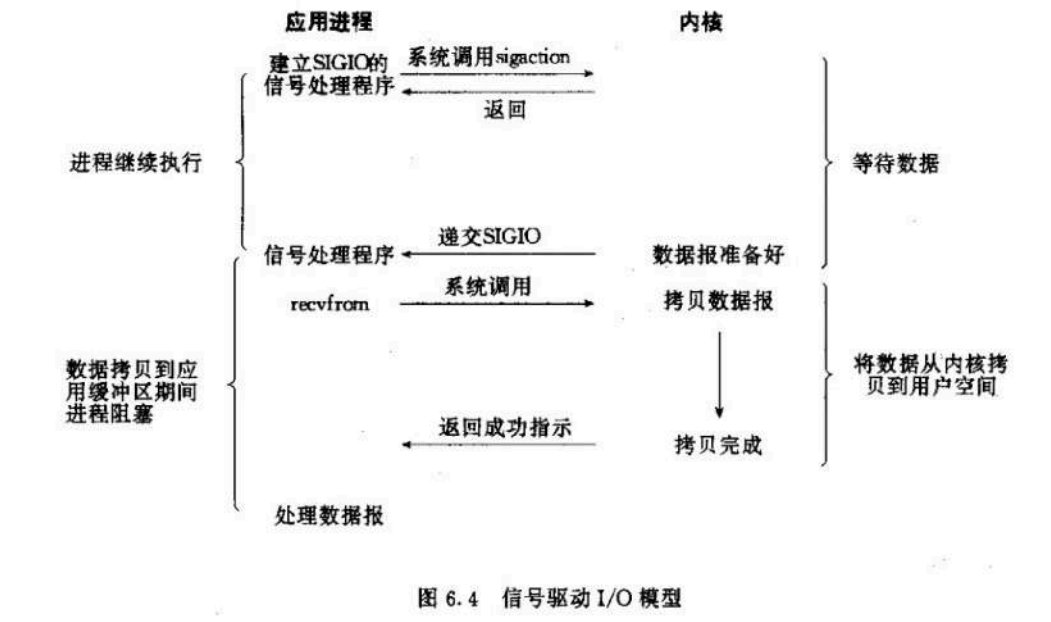
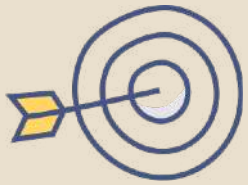


图 6.4 信号驱动 I/O 模型

* 基于信号实现 io 通知
* 用户程序注册一个信号handler，然后继续做后续的事情，当内核数据准备好了会发送一个信号，程序调用recvfrom进行系统调用将数据从内核空间拷贝到用户空间。
* 没见过有人用该模型 😅



aio 模型

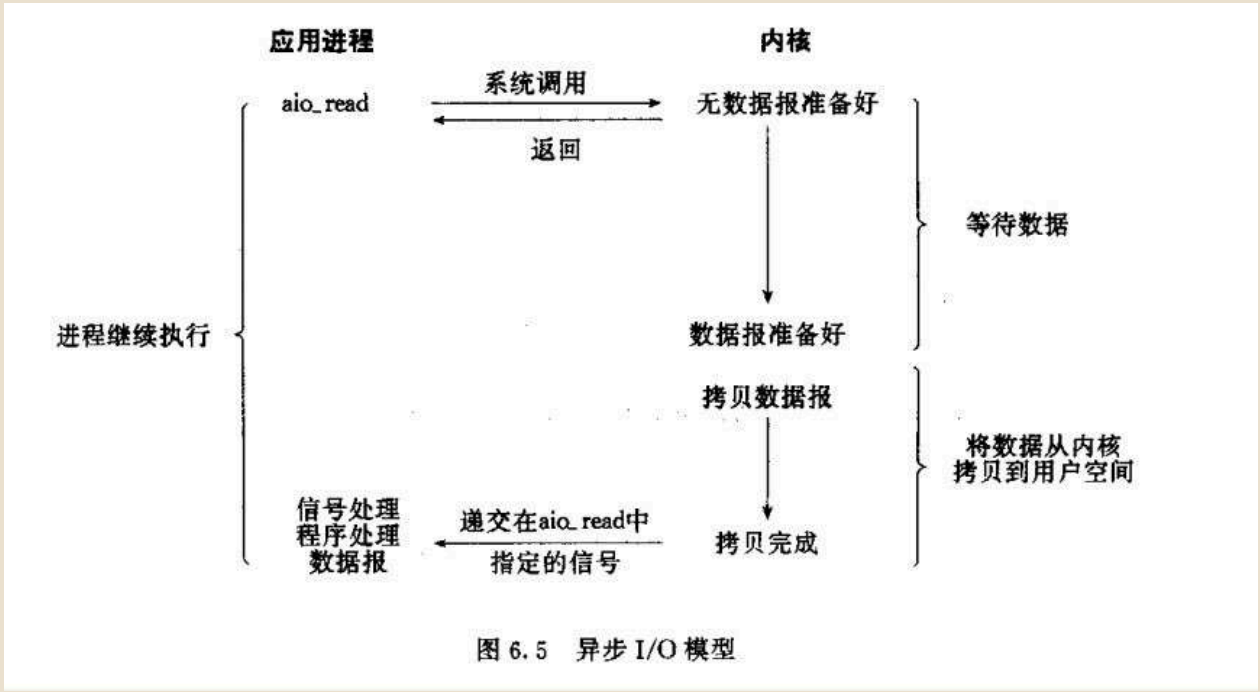
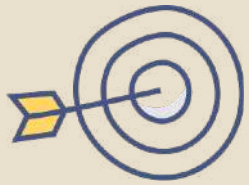


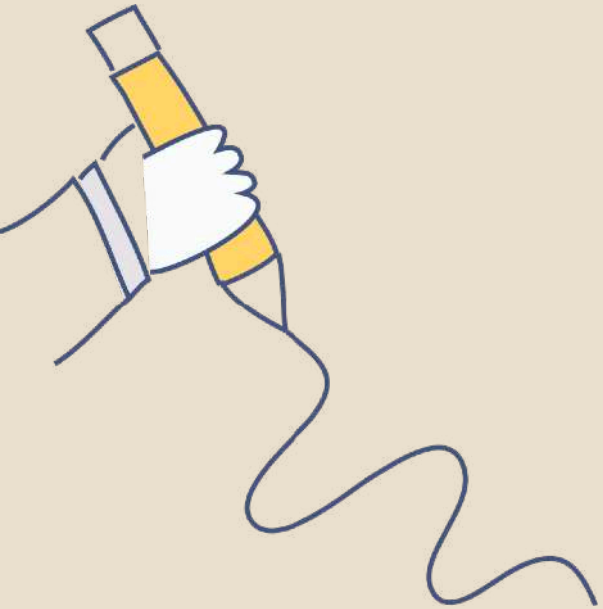
图 6.5　异步 I/O 模型

* aio_read产生系统调用，kernel在数据准备好后将数据从内核空间拷贝到用户空间，返回一个信号告知数据成功 ；

* 业务进程无需 block 进程去同步读取，内核帮你把数据 read 读取 ；

aio 为异步非阻塞 !!!





IO 多路复用

select

```
  sockfd = socket(AF_INET, SOCK_STREAM, 0);
  memset(&addr, 0, sizeof (addr));
  addr.sin_family = AF_INET;
  addr.sin_port = htons(2000);
  addr.sin_addr.s_addr = INADDR_ANY;
  bind(sockfd,(struct sockaddr*)&addr ,sizeof(addr));
  listen (sockfd, 5);

  for (i=0;i<1024;i++)
  {
    memset(&client, 0, sizeof (client));
    addrlen = sizeof(client);
    fds[i] = accept(sockfd,(struct sockaddr*)&client, &addrlen);
    if(fds[i] > max)
        max = fds[i];
  }

  while(1){
    FD_ZERO(&rset);
    for (i = 0; i< 1024; i++ ) {
        FD_SET(fds[i],&rset);
    }

    select(max+1, &rset, NULL, NULL, NULL);

    for(i=0;i<1024;i++) {
        if (FD_ISSET(fds[i], &rset)){
            memset(buffer,0,MAXBUF);
            read(fds[i], buffer, MAXBUF);
        }
    }
  }
  return 0;
}
```

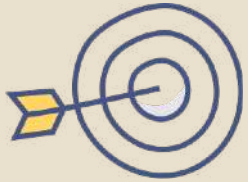
- 最大文件描述符限制，32bit 为 1024 ，64bit 为 2048
- fd_set 不可重用，每次调用都需要设置
- 用户态和内核态拷贝传递 fd_set
- O(n) 时间复杂度来轮询判断是否有事件

简单粗暴

poll

```c
struct pollfd {
    int fd;
    short events;
    short revents; // 可重用
};

int poll(struct pollfd *ufds, unsigned int nfds, int timeout);
```

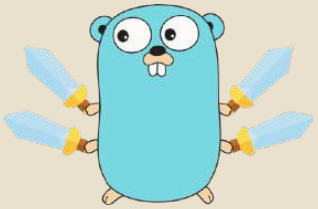
* 解决了 select fd_size 限制
* 无需来回重置 fd_set 事件标志
* 但fd集合仍需要传递
* 依旧需要 遍历轮询 判断事件



epoll

```
struct eventpoll {
    spin_lock_t lock;
    struct mutex mtx;

    // 等待队列
    wait_queue_head_t wq;

    // 事件满足条件的链表
    struct list_head rdllist;

    // 用于管理所有fd的红黑树
    struct rb_root rbr;
}
```

* 没有文件数量限制
* 基于回调通知机制，无需轮询事件，只需遍历就绪 ready list 表
* 存放 epitem 的红黑树存在于内核空间中
* 可动态地添加/删除/修改事件，不再像select/poll那样每次都要重设好所有事件标志



epoll event

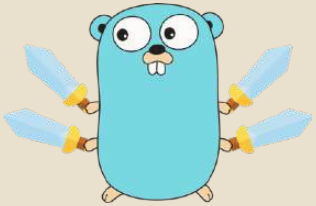
- 事件 Event
  - EPOLLIN 读事件
  - EPOLLOUT 写事件
  - EPOLLET 边缘触发模式
  - EPOLLLT 水平触发模式
  - EPOLLRDHUP, EPOLLHUP 连接异常
  - EPOLLERR 连接异常

```
struct epoll_event ev;
setnonblocking(cfd);
ev.data.fd = cfd;
ev.events = EPOLLIN | EPOLLET;
epoll_ctl(epfd, EPOLL_CTL_ADD, cfd, &ev);
```

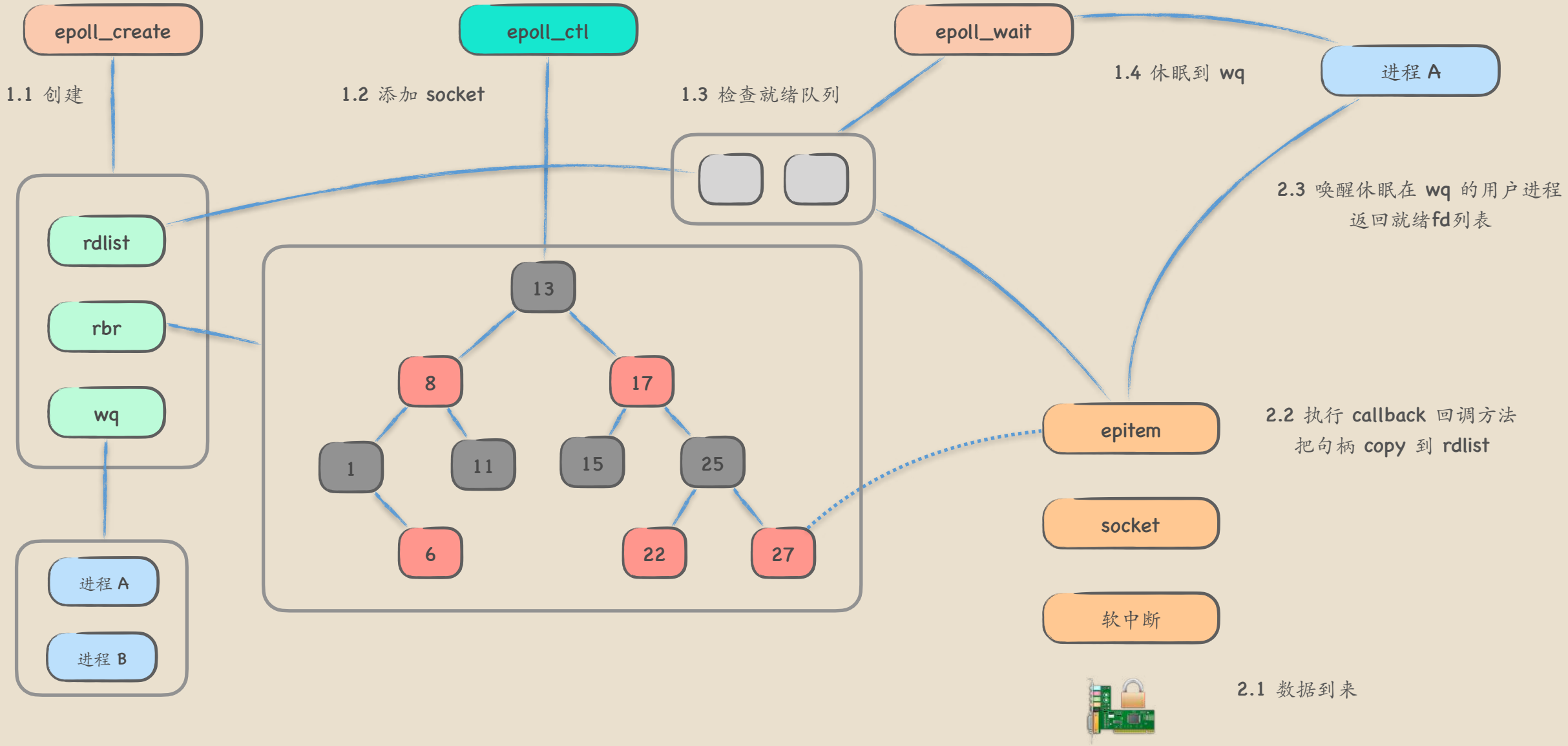
epoll

```
int epfd = epoll_create(POLL_SIZE);
struct epoll_event ev;
struct epoll_event *events = NULL;
nfds = epoll_wait(epfd, events, 20, 500);
{
    for (n = 0; n < nfds; ++n) {
        if (events[n].data.fd == listener) {
            //如果是主socket的事件的话，则表示有新连接进入了，进行新连接的处理。
            client = accept(listener, (structsockaddr *)&local, &addrlen);
            if (client < 0) {
                perror("accept");
                continue;
            }
            setnonblocking(client);        //将新连接置于非阻塞模式
            ev.events = EPOLLIN | EPOLLET; //并且将新连接也加入EPOLL的监听队列。

            ev.data.fd = client;
            if (epoll_ctl(epfd, EPOLL_CTL_ADD, client, &ev) < 0) {
                fprintf(stderr, "epollsetinsertionerror:fd=%d", client);
                return -1;
            }
        }
        else if(event[n].events & EPOLLIN)
        {
            // 对已连接的用户进行读取
            int sockfd_r;
            if ((sockfd_r = event[n].data.fd) < 0)
                continue;
            read(sockfd_r, buffer, MAXSIZE);
            ev.events = EPOLLOUT | EPOLLET;
            epoll_ctl(epfd, EPOLL_CTL_MOD, sockfd_r, &ev)
        }
        else if(event[n].events & EPOLLOUT)
        {
            // 可数据发送
            int sockfd_w = events[n].data.fd;
            write(sockfd_w, buffer, sizeof(buffer));
            ev.events = EPOLLIN | EPOLLET;
            epoll_ctl(epfd, EPOLL_CTL_MOD, sockfd_w, &ev)
        }

        ...
    }
}
```

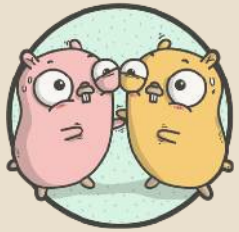
* epfd = epoll_create(intsize);
* epoll_ctl(int epfd, int op, int fd, struct epoll_event *event)
    * EPOLL_CTL_ADD
    * EPOLL_CTL_MOD
    * EPOLL_CTL_DEL
* epoll_wait(int epfd, struct epoll_event * events, intmaxevents, int timeout) ;



epoll desgin



epoll



* 水平触发 (level trigger)
* 开发相对简单
* 只要可读 (读缓冲区有数据) ,可写 (写缓冲区未满) 就一直可以拿到事件
* 当无数据可写时, 需要去除 epollout 事件, 不然一直触发 !

```
// 水平触发
evt.events = EPOLLIN;              // LT 水平触发 (默认) EPOLLLT
evt.data.fd = pfd[0];


// 边沿触发
evt.events = EPOLLIN | EPOLLET;    // ET 边沿触发
evt.data.fd = pfd[0];
```

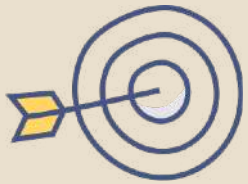
* 边缘触发 (edge trigger)
* 当有读事件到来变化才触发, 当缓冲区可写才触发 .
* 只会通知一次, 未处理就麻烦了
* 理论上性能比 lt 更好

当用户发送一个http请求, 服务端未读完或丢弃, 这时用户不再发送数据, 那么该fd就不会再通知 !

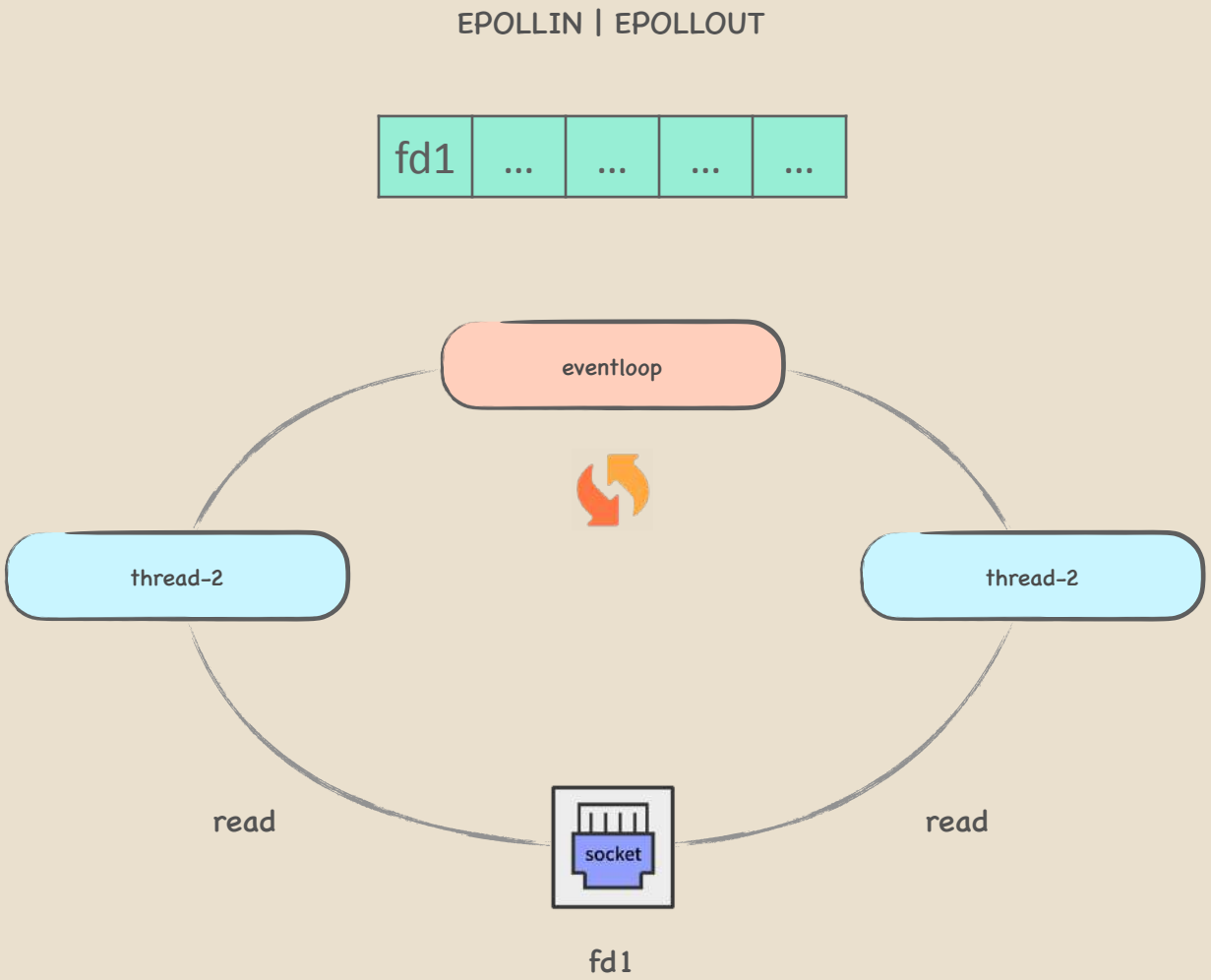
epoll

- 水平触发 lt
  - java nio
  - redis
  - muduo
  - skynet
  - tornado
  - golang gev
  - libevent (default)

- 边缘触发 et
  - nginx
  - envoy
  - mysql
  - netty (default)
  - golang net
  - golang gnet



epolloneshot




```c
void addfd(int epollfd,int fd,bool oneshot)
{
    epoll_event event;
    event.events = EPOLLIN | EPOLLET;
    event.data.fd = fd;
    if(oneshot)
    {
        event.events |= EPOLLONESHOT;
    }
    epoll_ctl(epollfd,EPOLL_CTL_ADD,fd,&event);
    set_nonblock(fd);
}

void reset_epolloneshot(int epollfd,int fd)
{
    epoll_event event;
    event.events = EPOLLIN | EPOLLET | EPOLLONESHOT;
    event.data.fd = fd;
    epoll_ctl(epollfd,EPOLL_CTL_MOD,fd,&event);
}
```

一个socket任何时刻都只被一个线程所处理

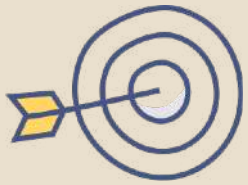
!!!

epolloneshop 只会触发一次，线程处理完后需要重置

epolloneshot，才可继续收到事件.

epoll

- epoll 不是线程安全的？
- epoll 通过 mmap 共享空间？
- epoll 是异步的？
- 如 epoll 使用阻塞 fd 读写？



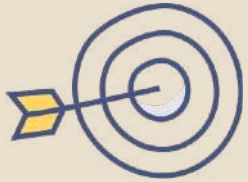
可监听的资源

- 可监听哪些资源？
  - sockfd
  - eventfd
  - timerfd
  - signalfd
  - inotifyfd
  - pipefd

- 不能监听普通文件 ???
  - 文件系统未实现 poll 接口
  - 磁盘始终是"Ready" 就绪状态

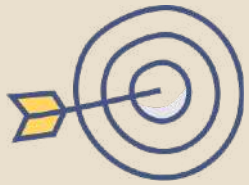

```c
#include <stdio.h>
#include <sys/epoll.h>
#include <fcntl.h>

int main()
{
    int epfd, fd;
    struct epoll_event ev, events[2];
    int result;

    epfd = epoll_create(10);
    if (epfd < 0) {
        perror("epoll_create()");
        return -1;
    }

    fd = open("./test.txt", O_RDONLY | O_CREAT);
    if (fd < 0) {
        perror("open()");
        return -1;
    }

    ev.events = EPOLLIN;

    result = epoll_ctl(epfd, EPOLL_CTL_ADD, fd, &ev);
    if (result < 0) {
        perror("epoll_ctl()");
        return -1;
    }

    epoll_wait(epfd, events, 2, -1);

    return 0;
}
```

epoll_ctl(): Operation not permitted



aio

- kernel native aio
  - 原生实现
  - nginx, mysql 有在使用
  - 只能使用 direct io 直接io
- glibc aio
  - 使用线程池实现 user 层异步io
  - 可以使用 buffer io 缓存io

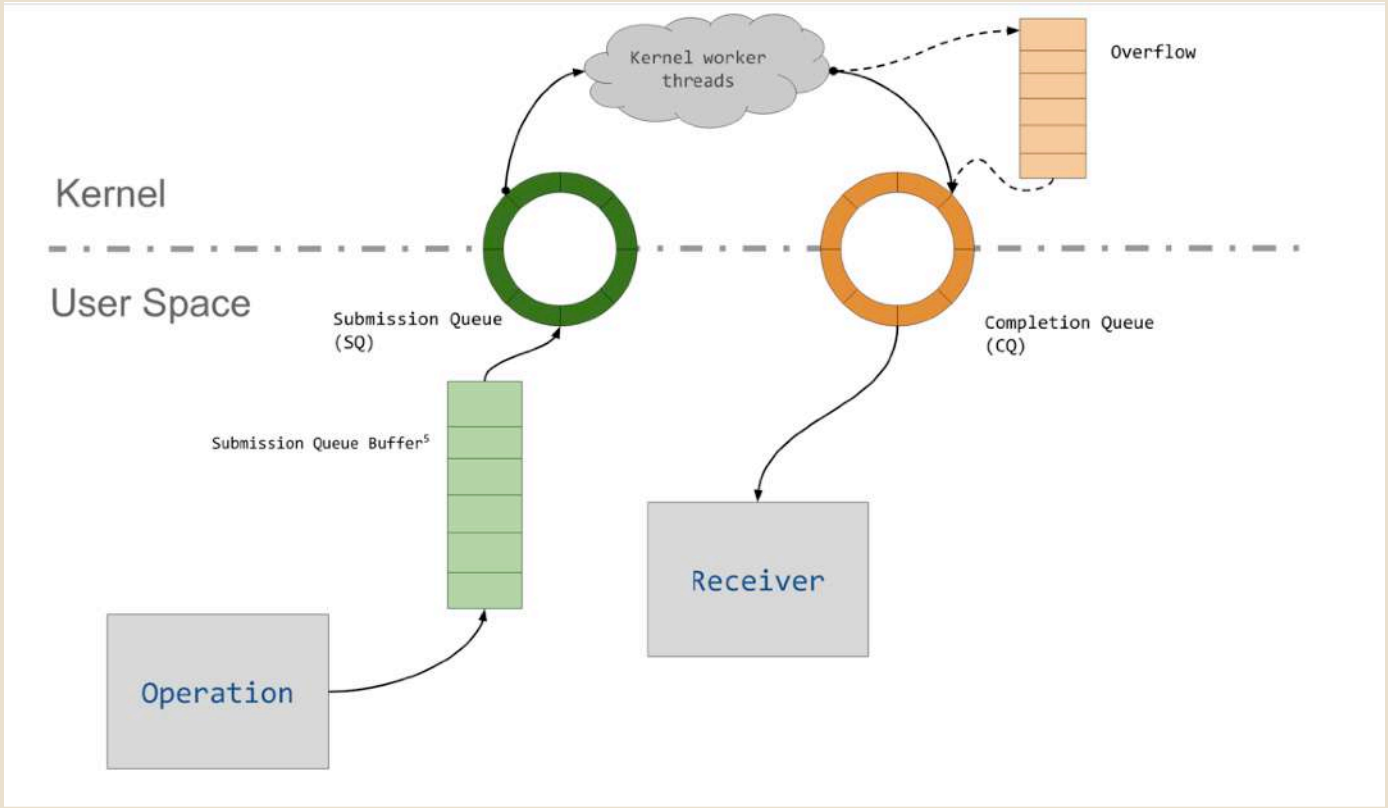


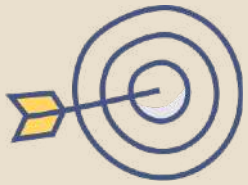
```
# nginx aio config

location /video/ {
    sendfile           on;
    aio                on;
    directio           8m;    !!!
    directio_alignment 4k;
}
```

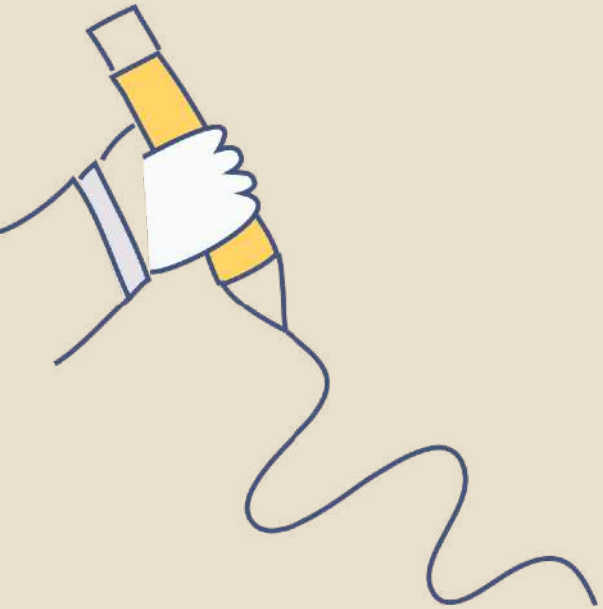
- nginx
  - nginx aio强制使用direct io
  - 通过文件大小策略走senfile和aio

io_uring

- io_uring (全新的系统级异步接口)
  - kernel 5.1 基础, kernel 5.6 完善
  - 可替换 epoll
  - 支持文件读写
  - 支持socket fd
  - mmap 映射
  - 支持 buffered io, libaio只支持direct io.



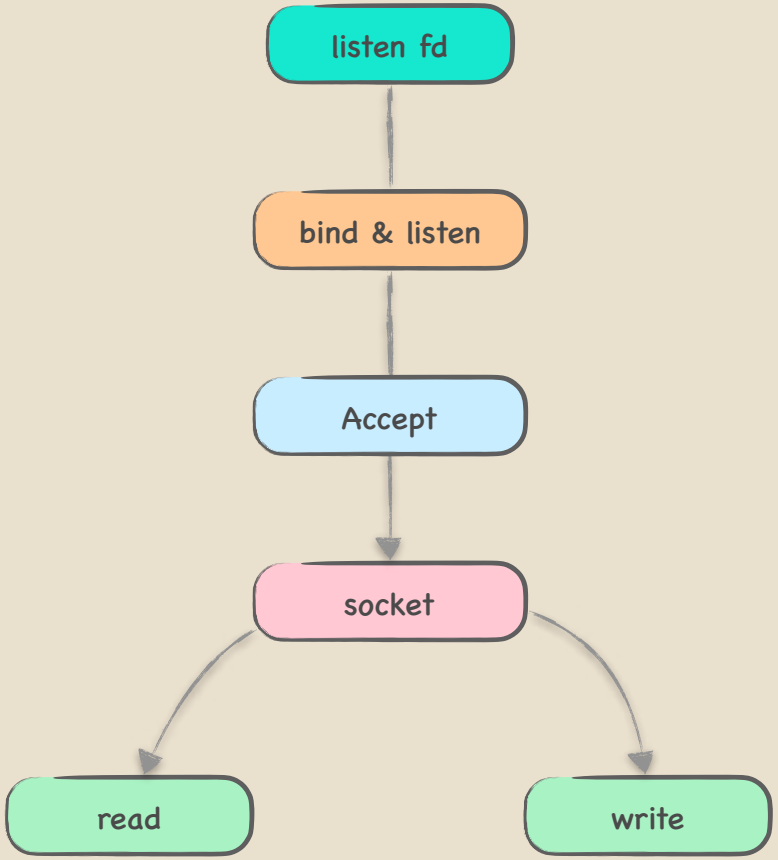




3

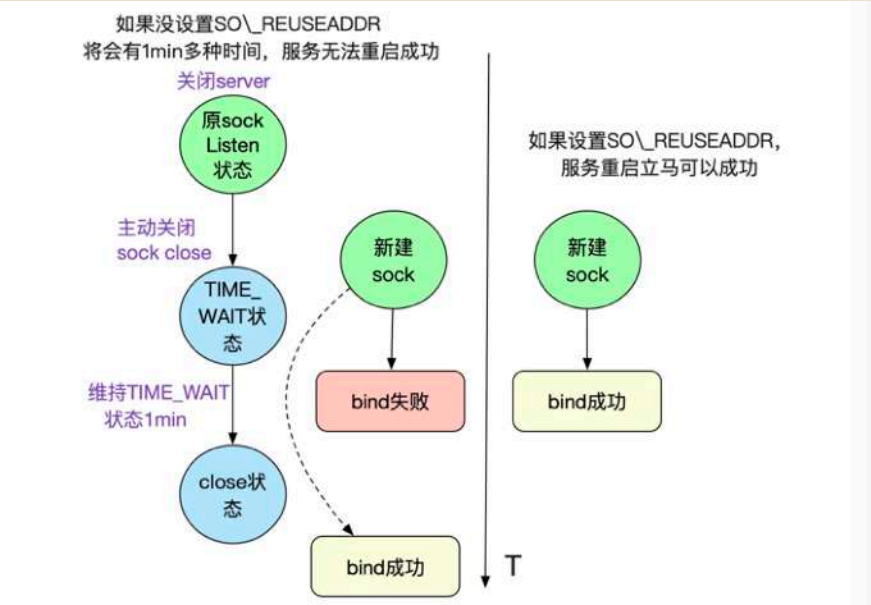
网络编程模型

code




```python
import socket
import sys

# Create a TCP/IP socket
sock = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
sock.setsockopt(socket.SOL_SOCKET, socket.SO_REUSEADDR, 1)
sock.setsockopt(socket.SOL_SOCKET, socket.SO_REUSEPORT, 1)

# Bind the socket to the address given on the command line
server_address = ('localhost', 10000)
sock.bind(server_address)
sock.listen(1)

while True:
    connection, client_address = sock.accept()
    try:
        print >>sys.stderr, 'client connected:', client_address
        while True:
            data = connection.recv(16)
            print >>sys.stderr, 'received "%s"' % data
            if data:
                connection.sendall(data)
            else:
                break
    finally:
        connection.close()
```

so_reuseaddr



- 比如服务端进程主动close退出，那么相关的连接被置为 time-wait 状态
- socket 对处于 time-wait 的套接字进行bind时，异常报错.
- 错误: "Address already in use"

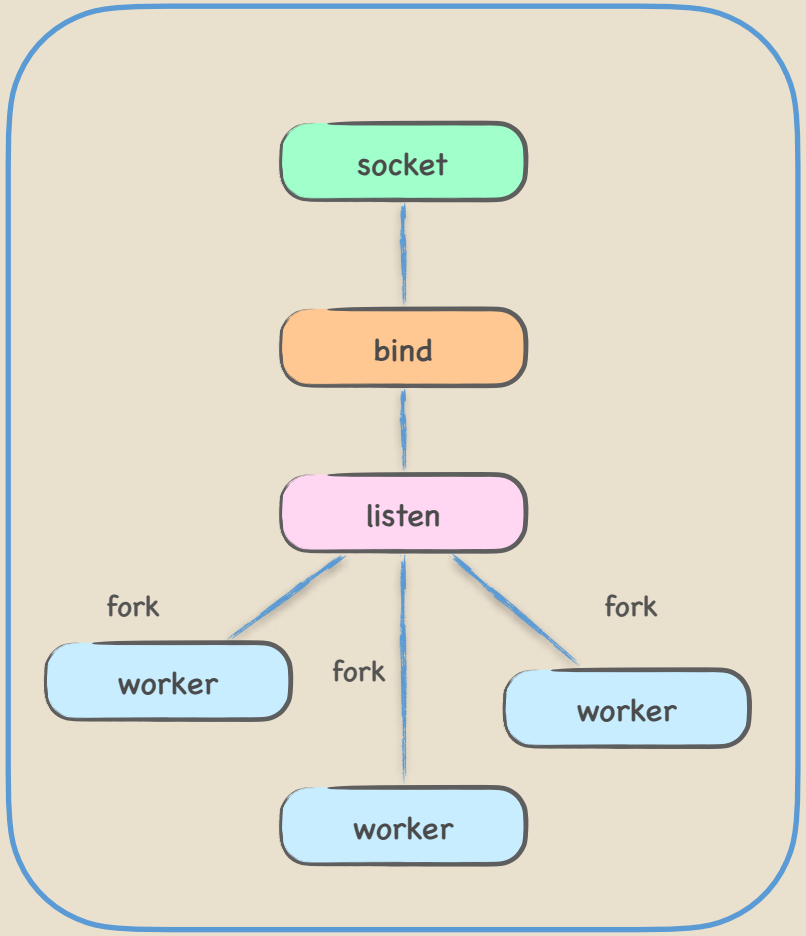
```
def main(self):
        server_sock = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
        server_sock.setsockopt(socket.SOL_SOCKET, socket.SO_REUSEADDR, 1)
        server_sock.setsockopt(socket.SOL_SOCKET, socket.SO_REUSEPORT, 1)

        server_sock.bind(('localhost', 8080))
        server_sock.listen(self.backlog_size)
        ...
```

用于对处在 time-wait 状态下的 socket 进行重新 bind

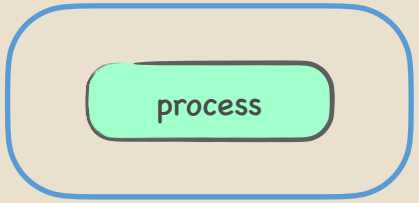
so_reuseport

- SO_REUSEPORT
  - 支持多个进程或者线程绑定到同一端口
  - 避免多个子进程竞争 listen fd (惊群) ?
  - 内核层面实现 listen worker 的负载均衡
  - 更容易实现平滑升级

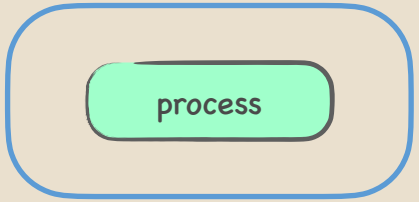
```
def main(self):
        server_sock = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
        server_sock.setsockopt(socket.SOL_SOCKET, socket.SO_REUSEADDR, 1)
        server_sock.setsockopt(socket.SOL_SOCKET, socket.SO_REUSEPORT, 1)

        server_sock.bind(('localhost', 8080))
        server_sock.listen(self.backlog_size)
        ...
```



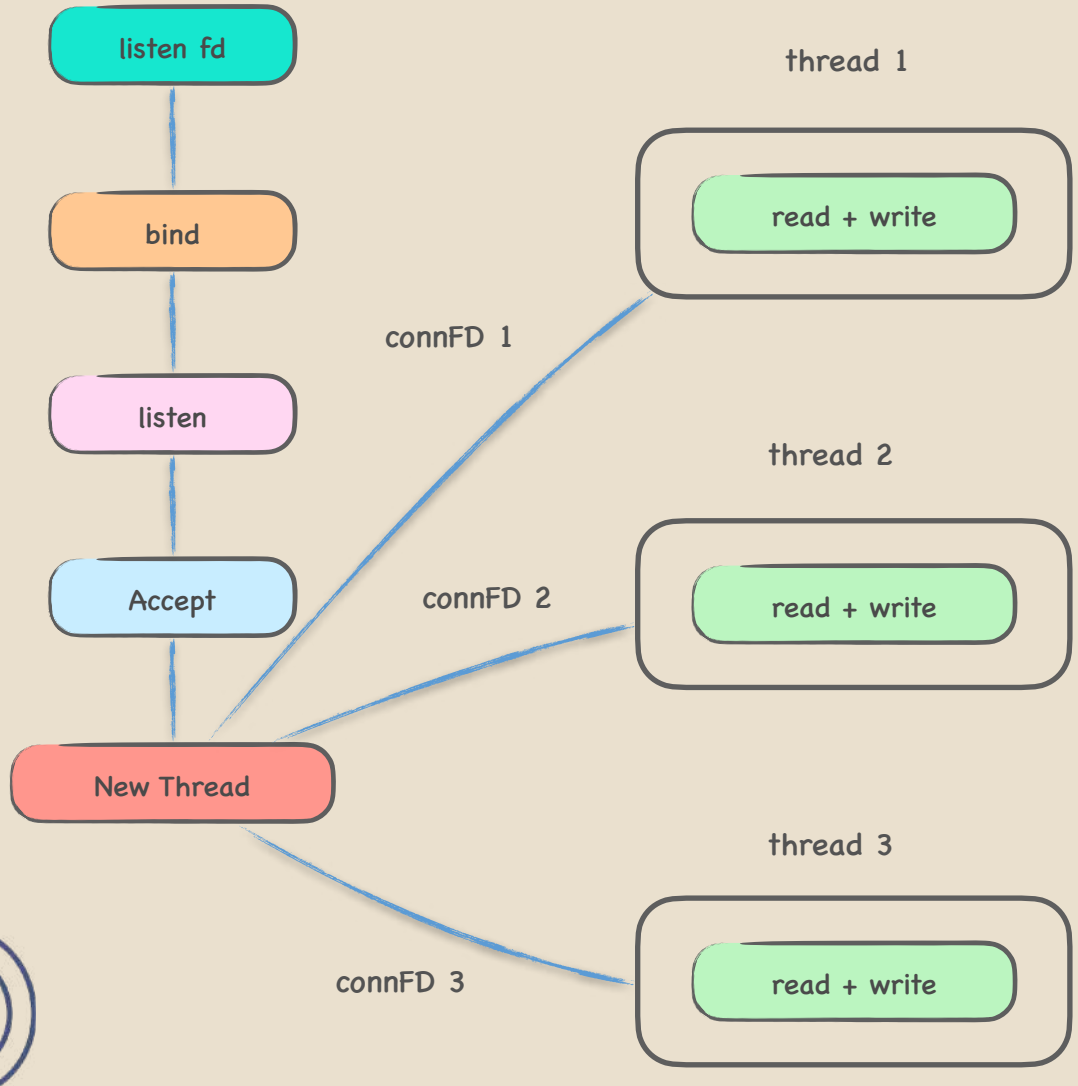
创建新进程且 listen



创建新进程且 listen

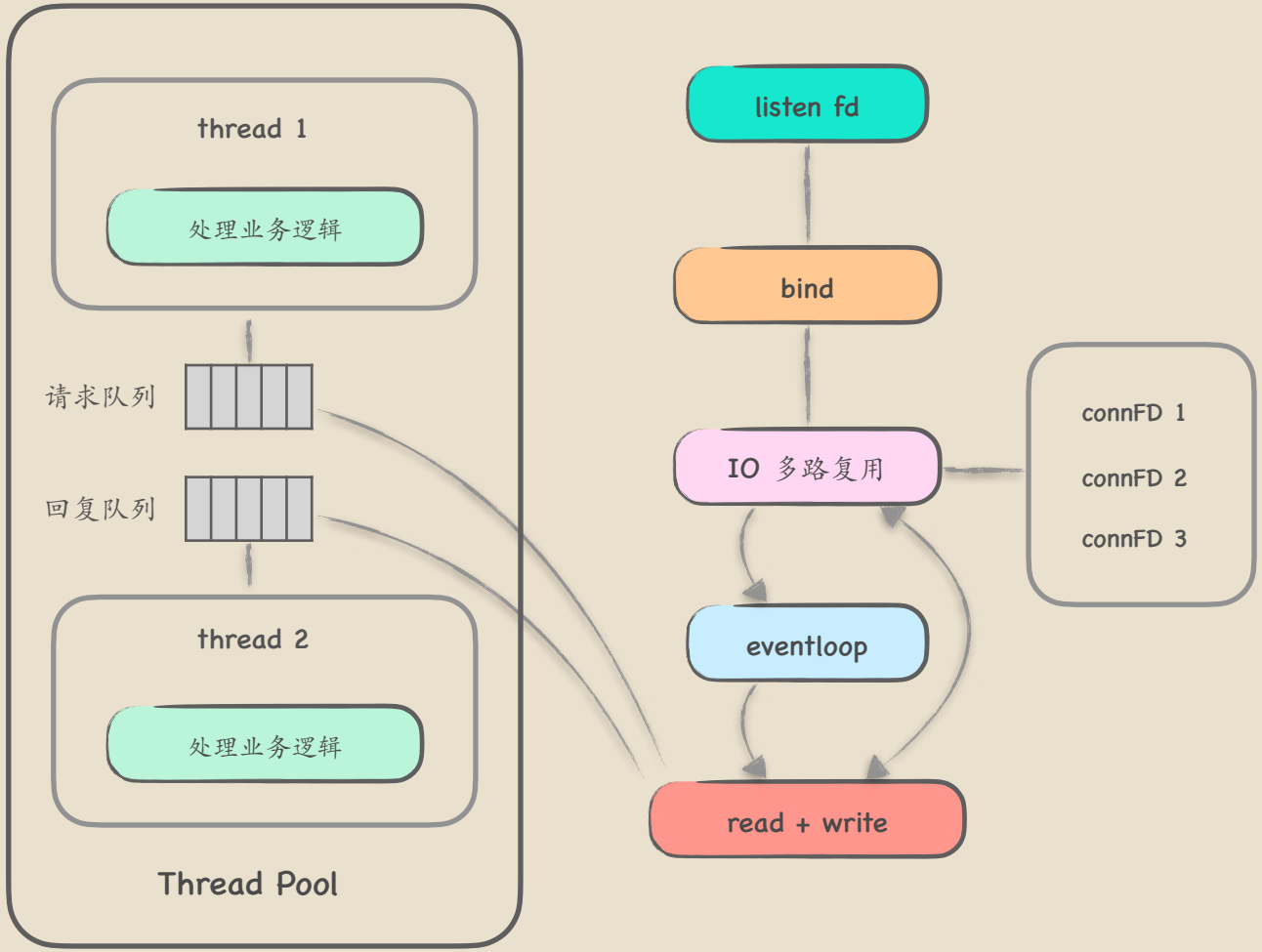


新线程模式



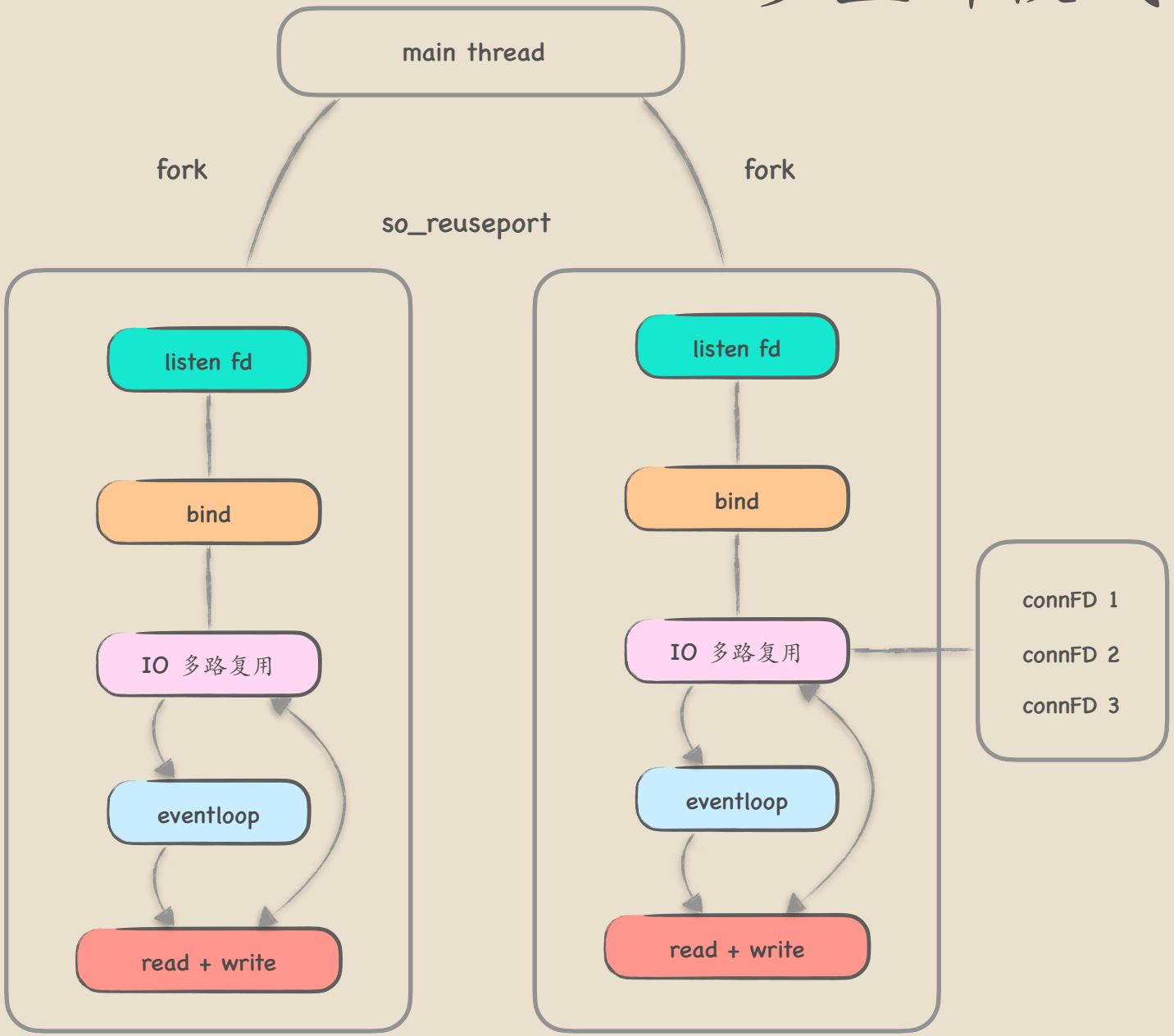
- 单线程Accept+多线程读写业务（无IO复用）
- 优点
  - 简单
  - 粗暴
- 缺点
  - 连接跟线程数成正比关系
  - 没法高并发

线程池模式



- 单线程多路复用 + 多线程业务工作池
- 操作过程
  1. eventloop 按照协议完整读取请求体
  2. 把请求体和conn传递给线程池队列
  3. 业务线程处理完后，写回复队列
  4. 由 eventloop 回复报文
- 优点
  - 以前的web框架多数是这样的
  - 将耗时的业务分离到工作线程池
- 缺点
  - 同时超过线程池数量的任务会排队等待！
  - socket 读写只有主线程来操作，网络单核心！

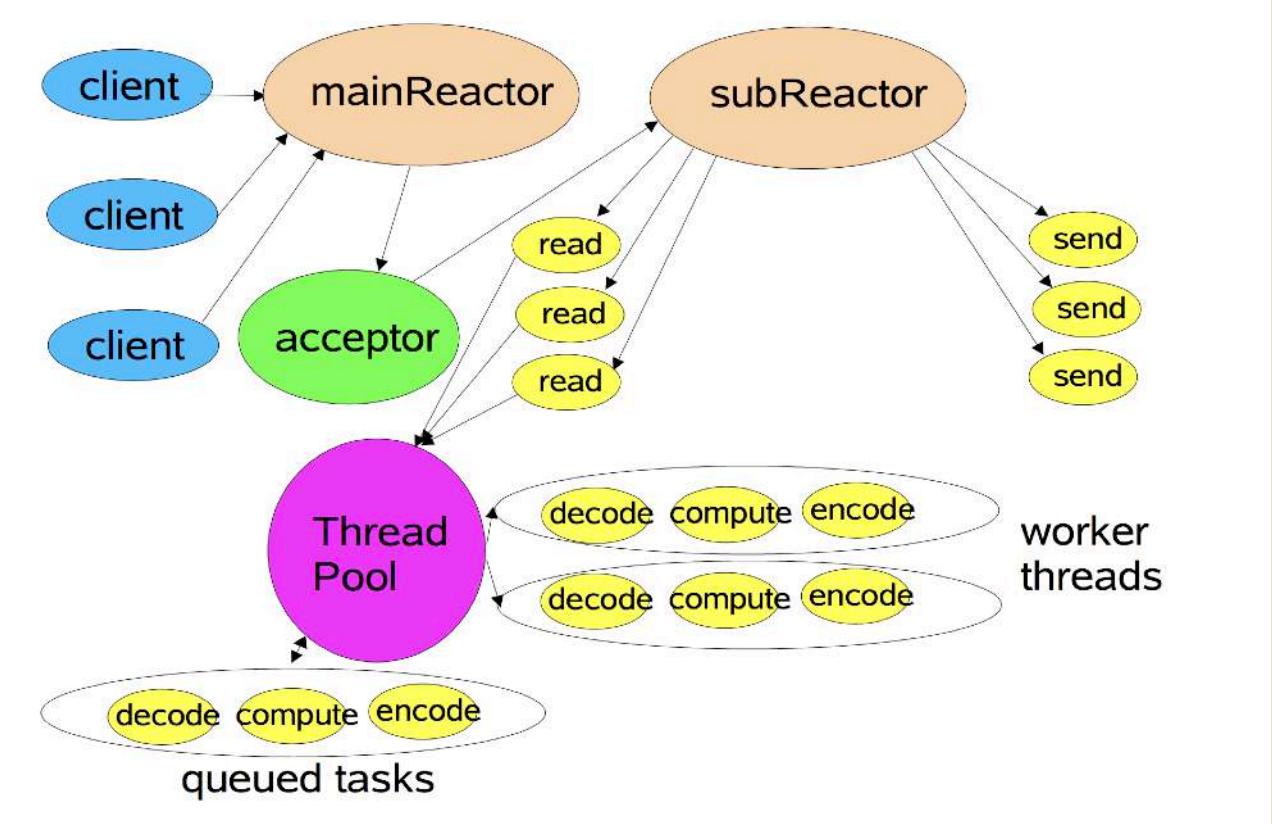
多监听模式



- 预先分配 worker 线程/进程的数量 .
- 通过 master 主进程来管理worker线程 .
- 每个线程为一个独立的 event-loop !!!
- nginx, haproxy 类似该模式 .

reactor

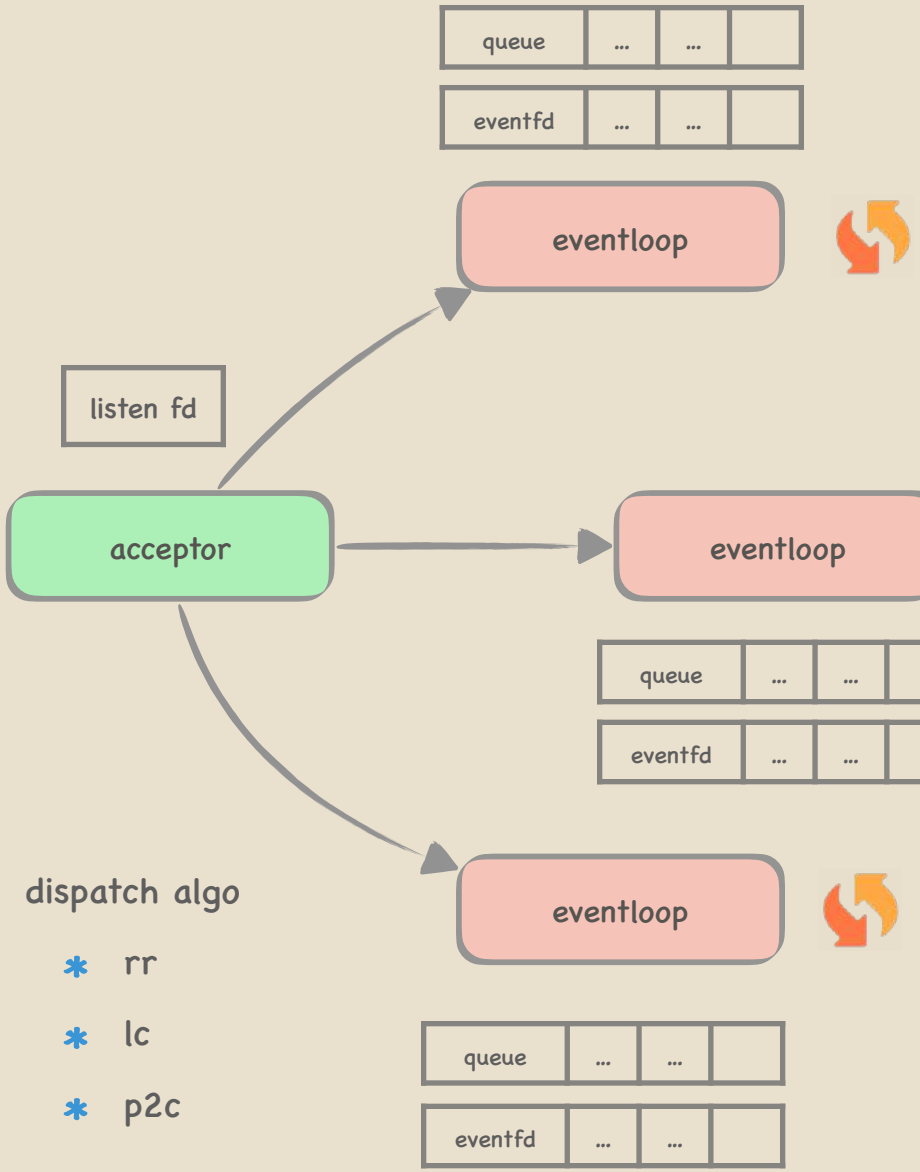
- java netty
- c++ muduo
- golang gnet
- golang gev
- ....



rawepoll

- OnConnection()
- OnMessage()
- OnClose()

connection
connection
connection
connection
connection



- dispatch algo
  - rr
  - lc
  - p2c

思考ing

可以参考 golang 的实现 !!!

* 😅 如果业务逻辑本身是阻塞的，把线程占满了 !!!
  * time.sleep(N)
  * query mysql, redis, http api
  * block queue
  * mutex / semaphore
  * disk io
  * ...

proactor

当发起 aio_read （异步 I/O） 之后，就立即返回，事件到来后，内核自动将数据从内核空间拷贝到用户空间，应用程序并不需要主动发起拷贝动作 !!!

* Reactor，同步非阻塞同步网络模式，感知的是就绪可读写事件
* Proactor，异步非阻塞模式，感知的是已完成的读写事件

AIO 异步模式 !!!

proactor

linux aio 不是很靠谱呀 !!!

- 为什么在linux都在使用 reactor 架构 😅
  - 不能实现 socket aio, 只能对文件进行 aio
  - 文件也只能是 direct io
- windows iocp 实现系统级别的 aio, 可实现高性能 proactor 架构

惊群问题

- 什么是惊群?
  - 同一个事件通知给多人，类似观察者模式
  - 造成无效唤醒线程，无故上下文切换
- accept 的惊群已在 kernel 2.6 解决！
- 多个 eventloop 同时监听一个 fd 造成epoll惊群

accept 是线程安全， 不会重复和丢事件！

```c
int worker_process(int listenfd, int epoll_fd, struct epoll_event *events,
                   int k) {
    while (1) {
        int n;
        n = epoll_wait(epoll_fd, events, MAXEVENTS, -1);
        printf("Worker %d pid is %d get value from epoll_wait\n", k, getpid());
        sleep(0.2);
        for (int i = 0; i < n; i++) {
            if ((events[i].events & EPOLLERR) || (events[i].events & EPOLLHUP) ||
              (!(events[i].events & EPOLLIN))) {
                printf("%d\n", i);
                fprintf(stderr, "epoll err\n");
                close(events[i].data.fd);
                continue;
            } else if (listenfd == events[i].data.fd) {
                struct sockaddr in_addr;
                socklen_t in_len;
                int in_fd;
                in_len = sizeof(in_addr);
                in_fd = accept(listenfd, &in_addr, &in_len);
                if (in_fd == -1) {
                    printf("worker %d accept failed\n", k);
                    break;
                }
                printf("worker %d accept success\n", k);
                close(in_fd);
            }
        }
    }

    return 0;
}
```

惊群问题

- epoll listen fd ?
  - “accept_mutex”，参考 nginx 的做法
  - reuseport 端口复用模式，每个worker都实例化监听 listen fd
  - epoll exclusive on Linux 4.5 +
    - 不够均衡
    - 内核总是唤醒等待队列的第一个 worker 进程

```
尝试获取accept锁

if 获取成功:
    在epoll中注册 listen fd
else:
    在epoll中取消监听 listen fd

处理所有事件 || 触发超时
释放accept锁
```

```
http {
    server {
        listen 80 reuseport;
        server_name  localhost;
        # ...
    }
}

stream {
    server {
        listen 81 reuseport;
        # ...
    }
}
```

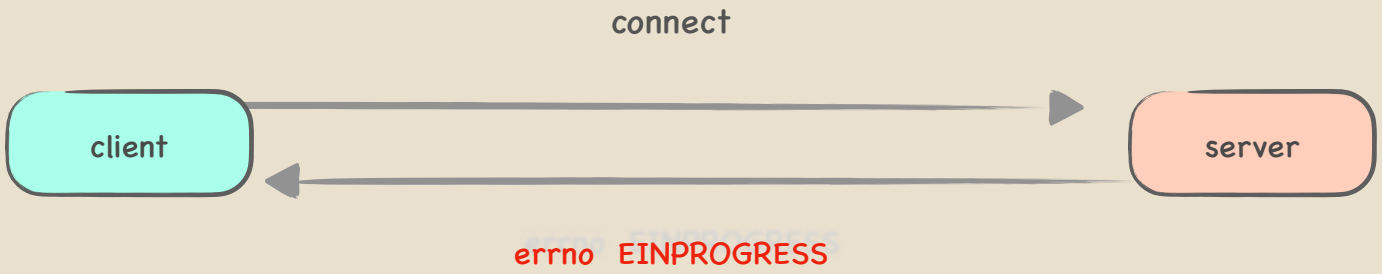
```
m_epollfd = epoll_create1(0);

ev.events = EPOLLIN|EPOLLEXCLUSIVE;
ev.data.fd = m_listenfd;

if(epoll_ctl(m_epollfd, EPOLL_CTL_ADD, m_listenfd, &ev) < 0)
{
    cout << "add listen socket to epoll err" << endl;
    exit(EXIT_FAILURE);
}
```

读写返回值

```
for(; ;)
{
        nfds = epoll_wait(epfd, events, 20, 500);
        for(i = 0; i < nfds; ++i)
        {
            if(events[i].data.fd == listenfd) {
                printf("accept connection, fd is %d\n", listenfd);
                ...
            }
            else if(events[i].events & EPOLLOUT) {
                ...
            }
            else if(events[i].events & EPOLLIN)
            {
                sockfd = events[i].data.fd;
                n = read(sockfd, line, MAXLINE);
                if(n == 0)
                {
                    printf("%s\n", "客户端断开连接。");
                    epoll_ctl(epfd, EPOLL_CTL_DEL, sockfd, &ev);
                    continue;
                }

                if(n > 0)
                {
                    printf("读到 %d 字节数据", n);
                    continue;
                }

                if (n < 0 && (errno == EAGAIN)
                {
                    printf("%s\n", "没有更多的数据可以读了");
                    continue;
                }

                printf("读异常，误代码为%d\n", errno);
                epoll_ctl(epfd, EPOLL_CTL_DEL, sockfd, &ev);
                ...
}
```

- errno
  - EINTR, 信号中断了系统调用
  - EAGAIN, 继续监听事件
  - EWOULDBLOCK, 同上（老系统接口有差异）
  - ECONNREST, tcp rst连接重置
  - EPIPE, 管道破裂
  - ETIMEDOUT, 连接超时
  - EINPROGRESS, 正在连接
  - ...
- N
  - > 0, 说明读到了N个字节的数据
  - = 0, 说明对端发起关闭
  - -1, 返回 errno 错误

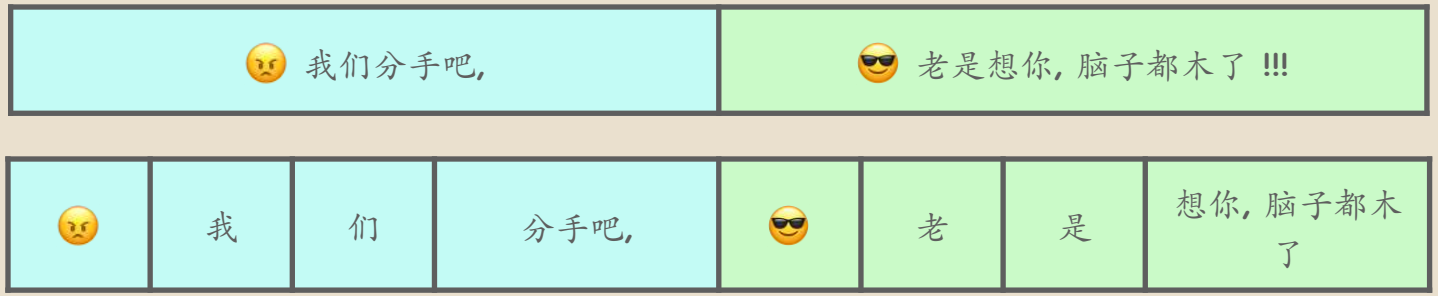
异步建立连接



* socket 配置非阻塞，发起 connect 连接
* 如 ret 返回0表示连接成功，如 -1 且 errno = EINPROGRESS 异步连接中
* 把该 fd 加入select或者epoll关心的 EPOLLOUT 事件
* 写事件触发后，需调用getsockopt去获取status，如果等于0说明非阻塞connect成功了，不为0那么连接异常，比如端口没开，ip找不到。

```c
# 异步建立连接
int res = connect(fd, ...);
if (res < 0 && errno != EINPROGRESS) {
    // error, fail somehow, close socket
    return;
}

if (res == 0) {
    // connection has succeeded immediately
} else {
    // connection attempt is in progress
}


# 加入 EPOLLOUT 事件
ev.events = EPOLLOUT|EPOLLET;
ev.data.fd = fd;
if (epoll_ctl(epfd, EPOLL_CTL_ADD, fd, &ev) == -1 ) {
        perror("epoll_ctl error");
}


# 监听事件并且getsockopt判断成功.
for (;;) {
        nevents = epoll_wait(epfd, events, EPOLL_MAXEVENTS, -1);
        if (nevents < 0) {
            perror("epoll_wait failed");
        }

        for (i = 0; i < nevents; i++) {
            if (events[i].data.fd == fd) {
                int result;
                socklen_t result_len = sizeof(result);
                if (getsockopt(fd, SOL_SOCKET, SO_ERROR, &result, &result_len) < 0) {
                    perror("getsockopt")
                    return;
                }

                if (result != 0) {
                    perror("connection failed; error code is in 'result'")
                    return;
                }

                // result == 0
                // 连接成功了，socket 可读可写.
            }
        }
}
```

粘包半包



- 半包, 一条数据, 被拆分发送, 对端分了多次读完
- 粘包, 多条数据, 被对方一下都读出来了

- 原因多种多样
  - mtu/mss (1500/1460)
  - nagle
  - rto / ofo
  - network delay
  - 分多次来 socket.send()
  - . . .

tlv

粘包半包

```
# redis
# set mykey myvalue
"*3\r\n$3\r\nSET\r\n$5\r\nmykey\r\n$7\r\nmyvalue\r\n"

# http length
HTTP/1.1 200 OK
Content-Length: 1111
Connection: keep-alive
Server: Apache

# http chunked
HTTP/1.1 200 OK
Transfer-Encoding: chunked
5\r\n
Media\r\n
8\r\n
Services\r\n
4\r\n
Live\r\n
0\r\n
\r\n
```

```go
type Package struct {
    Version        [2]byte // 协议版本
    Length         int16   // 数据部分长度
    Timestamp      int64   // 时间戳
    HostnameLength int16   // 主机名长度
    Hostname       []byte  // 主机名
    TagLength      int16   // Tag长度
    Tag            []byte  // Tag
    Msg            []byte  // 数据部分长度
}

func (p *Package) Pack(writer io.Writer) error {
    var err error
    err = binary.Write(writer, binary.BigEndian, &p.Version)
    err = binary.Write(writer, binary.BigEndian, &p.Length)
    err = binary.Write(writer, binary.BigEndian, &p.Timestamp)
    err = binary.Write(writer, binary.BigEndian, &p.HostnameLength)
    err = binary.Write(writer, binary.BigEndian, &p.Hostname)
    err = binary.Write(writer, binary.BigEndian, &p.TagLength)
    err = binary.Write(writer, binary.BigEndian, &p.Tag)
    err = binary.Write(writer, binary.BigEndian, &p.Msg)
    return err
}

func (p *Package) Unpack(reader io.Reader) error {
    var err error
    err = binary.Read(reader, binary.BigEndian, &p.Version)
    err = binary.Read(reader, binary.BigEndian, &p.Length)
    err = binary.Read(reader, binary.BigEndian, &p.Timestamp)
    err = binary.Read(reader, binary.BigEndian, &p.HostnameLength)
    p.Hostname = make([]byte, p.HostnameLength)
    err = binary.Read(reader, binary.BigEndian, &p.Hostname)
    err = binary.Read(reader, binary.BigEndian, &p.TagLength)
    p.Tag = make([]byte, p.TagLength)
    err = binary.Read(reader, binary.BigEndian, &p.Tag)
    p.Msg = make([]byte, p.Length-8-2-p.HostnameLength-2-p.TagLength)
    err = binary.Read(reader, binary.BigEndian, &p.Msg)
    return err
}
```

golang pack/unpack

udp 没有粘包半包的风险 !!!

粘包半包

- udp 面向消息通信，有保护消息边界
- 内核协议栈不会对 udp 做消息合并处理
- 发送端发了 10 次消息，接收端就需要读10次

- udp 最大包不能超过 65507 byte
- 建议把 udp 拆分成小包，规避 IP层 的分包重组
  - 包太大被 mtu 分包，多个包中有一个丢包，其他包被接收层丢弃 !!!
  - 更好的适配三方的可靠性传递 (kcp, quic)
  - 大包在网络中太危险，容易被过滤
- 建议对 udp 做 tlv 处理，业务上更可控 !!!

close vd shutdown

shutdown()
一种优雅地单方向或者双方向关闭socket的方法.

close()
立即双方向强制关闭socket并释放相关资源.

- tcp_close()
  - 如果读缓冲区有数据，清空读写缓冲区，立即发送 rst 报文，跳过 tw 2msl 等待，直接进入 closed .
  - 如果读缓冲区为空，fin 报文跟写缓冲区的数据一起发送 .
- close() 可能存在的问题
  - 触发 rst 操作
  - 丢失一些数据

😅 也可以不 care !!!

tcp rst

- socket rst errno
  - connection reset by peer (errno = ECONNRESET)
    - 收到对方的连接重置
  - broken pipe (errno = EPIPE)
    - 往一个已收到rst的连接写数据
    - 内核触发 sigpipe 信号，默认行为是干掉进程，but ...
- 多数网络框架劫持 sigpipe 信号行为，上层只需控制异常
- 做好异常处理，没什么毛病 !!!

半关闭

* 发送方：send() > shutdown(WR) > 监听读事件 > recv() == 0 （由接收方close 导致） > close()

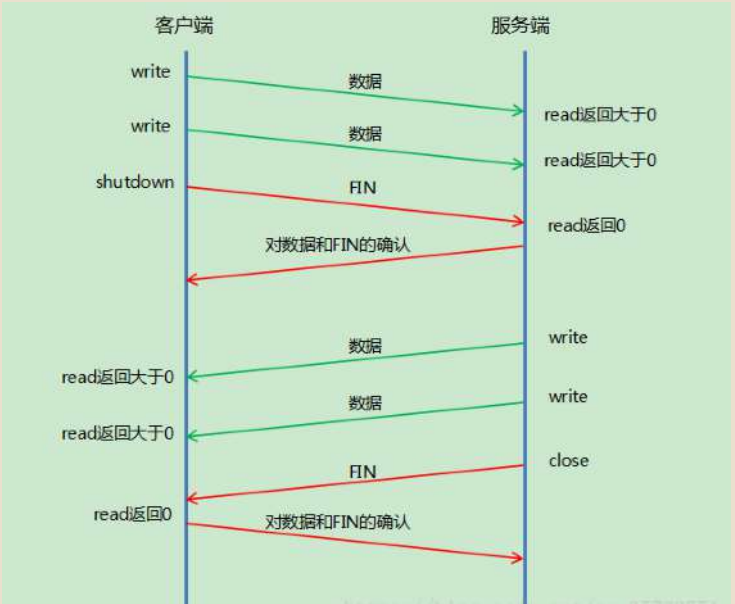
* 接收方：recv() == 0 （由发送方 shutdown 导致） > more to send? > close()

* SHUT_WR 关闭写方向，A发送给B一个FIN包，A不在发送数据给B，但B可以发送数据给A，且A可以接收报文

* SHUT_RD 关闭读方向，A 不在读取数据，若B任然给A发送数据，那么A给B发送RST

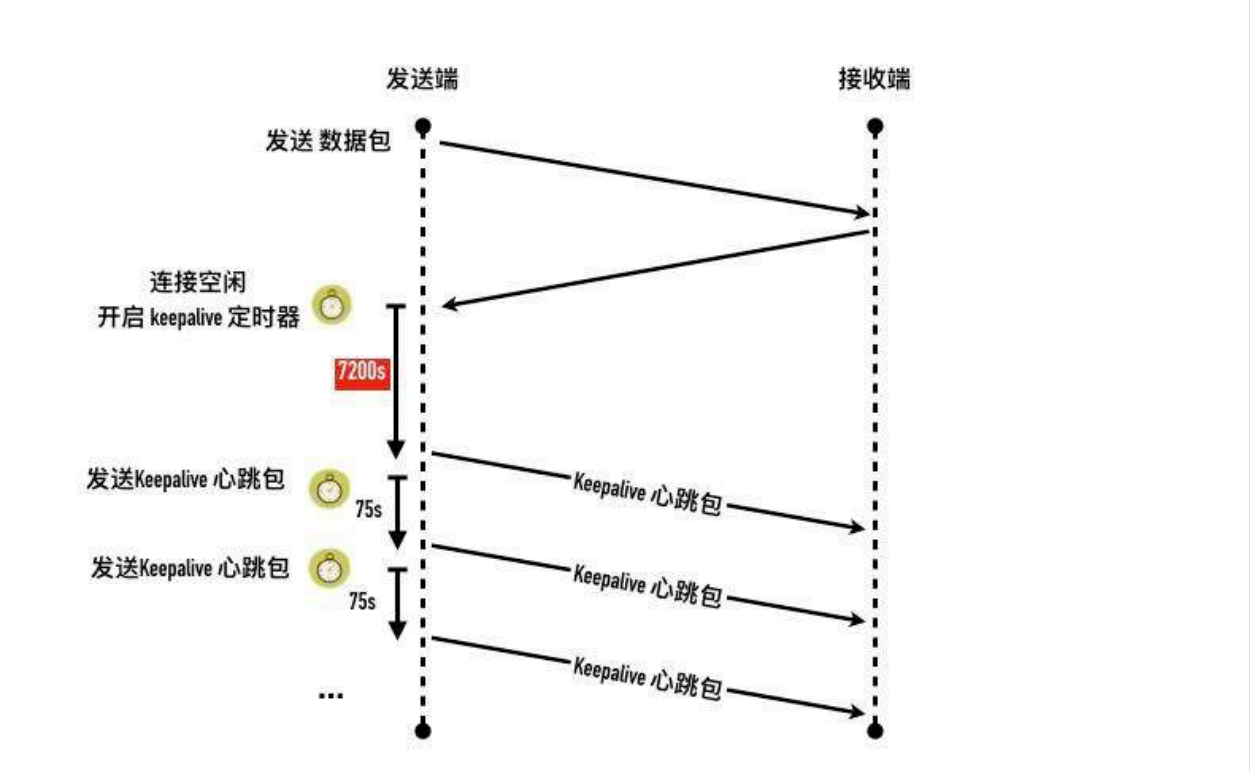
* SHUT_RDWR 关闭读写方向，A 发 FIN 给 B，A 不发送数据给 B，若B发送数据给A，由于已经关闭读写，A回应rst

shut_wr 就是 半关闭 !!!



默认心跳配置

- sysctl -a
  - net.ipv4.tcp_keepalive_time = 7200
    - 空闲7200秒后才开启保活检测
  - net.ipv4.tcp_keepalive_intvl = 75
    - 每次间隔 75s
  - net.ipv4.tcp_keepalive_probes = 9
    - 共尝试9次
- 最少需要 2 小时 11 分 15 秒 才可判定连接死亡！



nima, 时间太长了 !!!

如何设置心跳

- 直接调整 sysctl 的 keepalive 时间间隔；
- 在服务端对每个 socket opt 配置心跳；
- 在应用层自定义心跳；

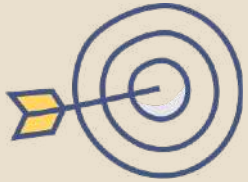
三种设置的方法 !!!

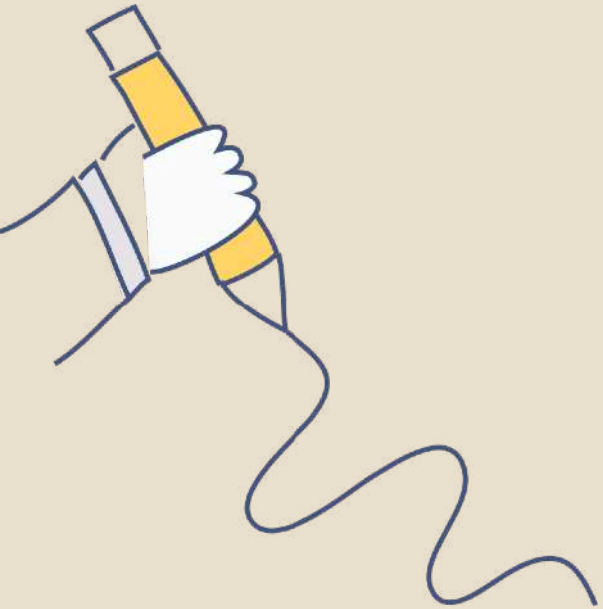
```python
import socket

server = socket.socket()
server.bind(('localhost', 9999))
server.listen(5)

while True:
    client, addr = server.accept()
    client.setsockopt(socket.SOL_SOCKET, socket.SO_KEEPALIVE, 1)
    client.setsockopt(socket.SOL_TCP, socket.TCP_KEEPIDLE, 120)
    client.setsockopt(socket.SOL_TCP, socket.TCP_KEEPCNT, 9)
    client.setsockopt(socket.SOL_TCP, socket.TCP_KEEPINTVL, 20)
```

```
09:45:53.433577 IP 127.0.0.1.9999 > 127.0.0.1.41834: Flags [.], ack 1, win 512, options [nop,nop,TS val
3173718853 ecr 3173598853], length 0
09:45:53.433600 IP 127.0.0.1.41834 > 127.0.0.1.9999: Flags [.], ack 1, win 512, options [nop,nop,TS val
3173718853 ecr 3173598853], length 0
09:47:53.433582 IP 127.0.0.1.9999 > 127.0.0.1.41834: Flags [.], ack 1, win 512, options [nop,nop,TS val
3173838853 ecr 3173718853], length 0
09:47:53.433614 IP 127.0.0.1.41834 > 127.0.0.1.9999: Flags [.], ack 1, win 512, options [nop,nop,TS val
3173838853 ecr 3173598853], length 0
09:49:53.433576 IP 127.0.0.1.9999 > 127.0.0.1.41834: Flags ...
```

应用层心跳

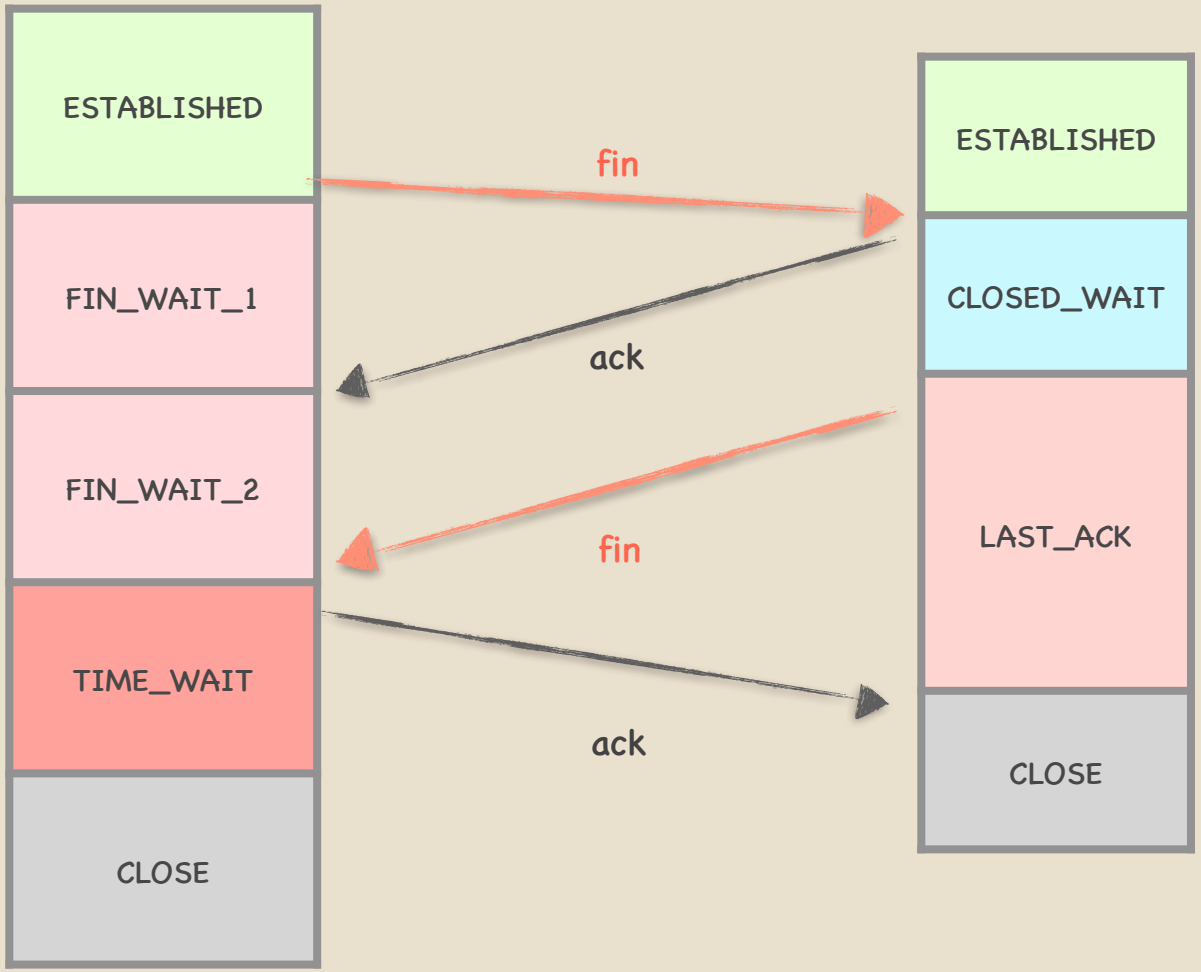
- 为什么要应用层心跳？
  - tcp keepalive 报文可能被设备特意过滤或屏蔽，如运营商设备；
  - tcp keepalive 由内核帮忙回复，无法检测应用层状态, 如进程阻塞、死锁、TCP缓冲区满等情况；
  - 应用层的心跳包可以顺便携程业务数据；
  - tcp keepalive 不方便判断连接被关闭的原因；





4 常见问题

常见问题



* 为什么会出现大量的 time_wait ?
* 为什么会出现大量的 closed_wait ?

time-wait

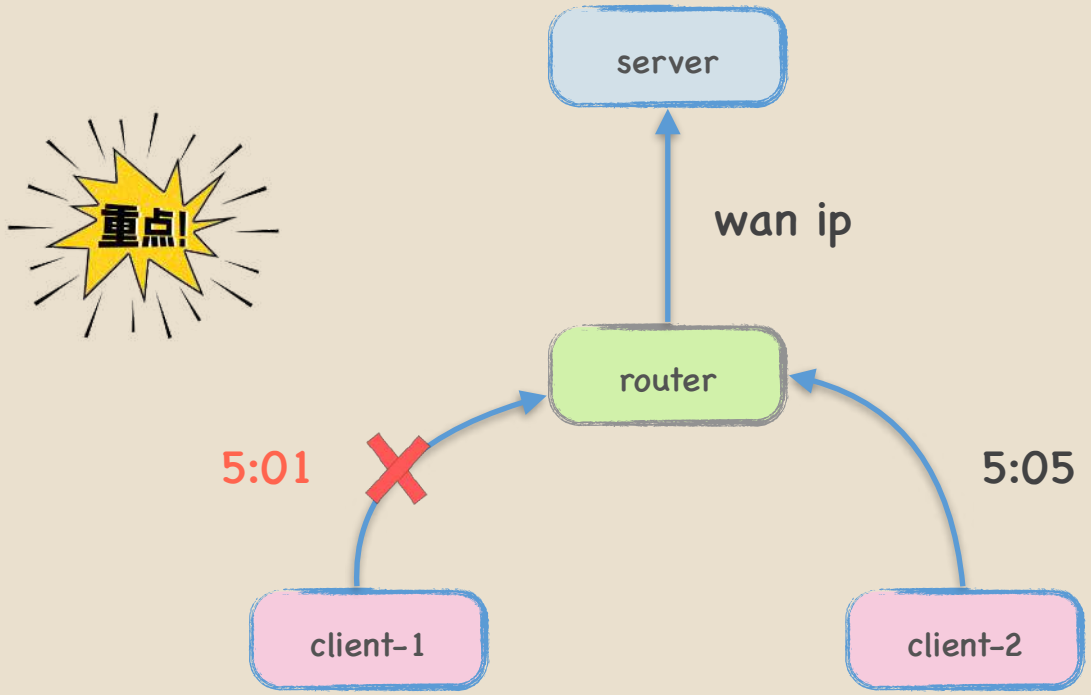
根本问题在于
为什么有大量的time-wait
!!!

- 短连接？
- 连接池爆满？
- 应用协议异常？
- 超过idle timeout？
- ...

- 为何跟 time-wait 过不去？
  - socket占用缓冲区内存 ？
  - 占用进程 RSS 内存？
  - 占用local_range_port？
  - 无法申请地址 ？

time-wait

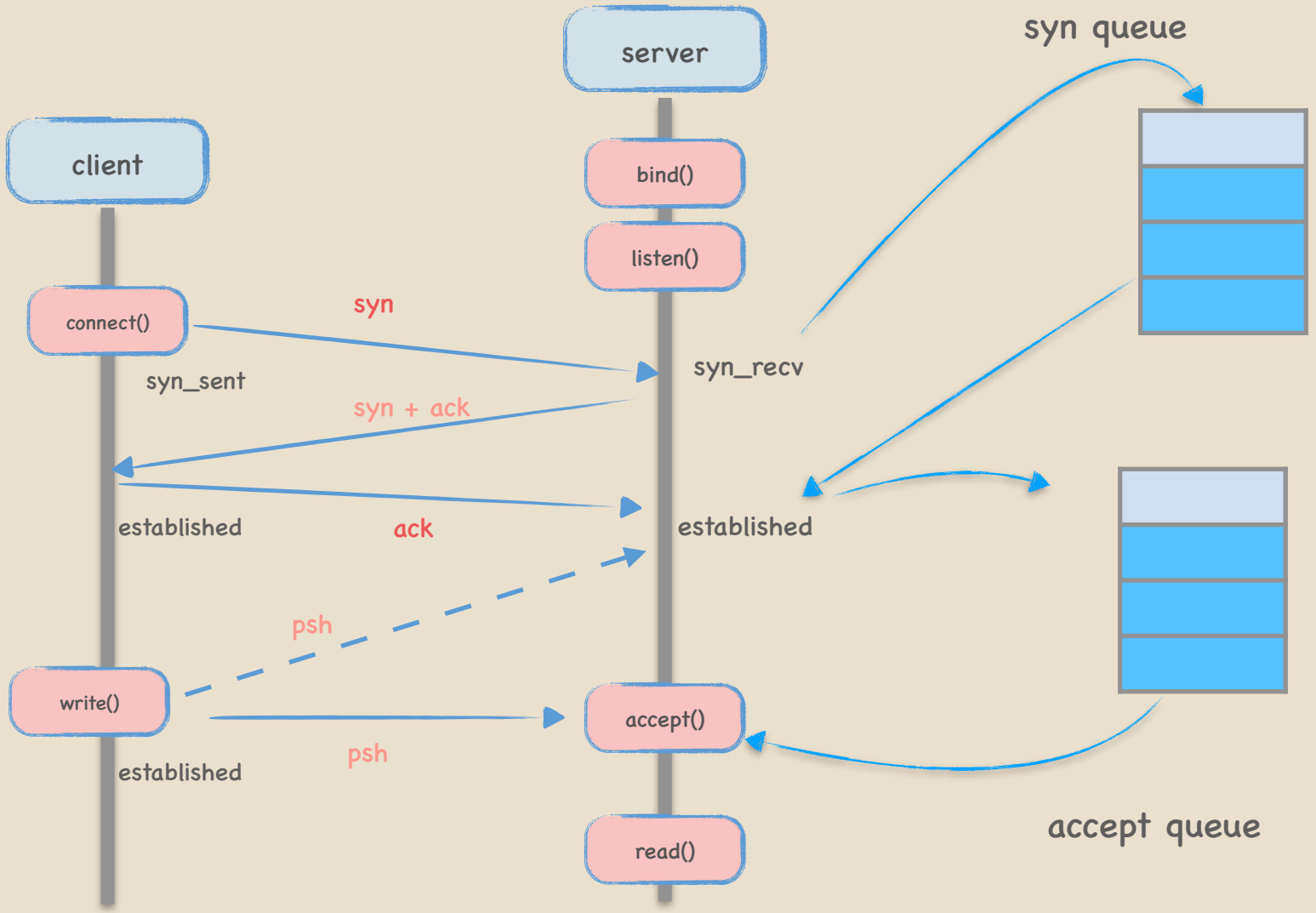
- net.ipv4.tcp_tw_recycle = 1
  - 不要开, 不要开，不要开 !!!
  - nat环境有大问题 !!!
  - linux 4.12 会移除该配置 !!!
- tcp_tw_reuse=1
  - 安全选项
  - 一秒后复用tw状态的端口
- 适当优化 tcp_max_tw_buckets



client1时间晚于client2, client2 先于server 建联，client1会失败 !!!

server 开启 tw_recycle 和 timestamp配置，启用per-host的paws机制.

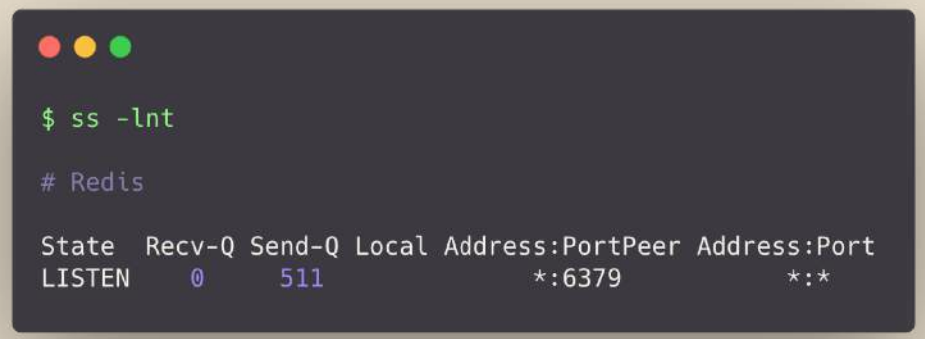
连接队列



* 半连接队列
  * 收到第一个syn
  * 回复syn + ack
* 全连接队列
  * 完成三次握手
  * 并未accept取走

连接队列

- 半连接队列
  - tcp_max_syn_backlog (1024)
  - 其实跟三个值都有关系
    - backlog、net.ipv4.tcp_max_syn_backlog、net.core.somaxconn (内核代码有描述)



- 全连接队列
  - get min value
  - listen(backlog)
    - Nginx = 511
    - Redis = 511
  - net.core.somaxconn (128)
- accept原子消费且不惊群
- 还在全队列的连接可接收数据
- 超出则拒绝建连

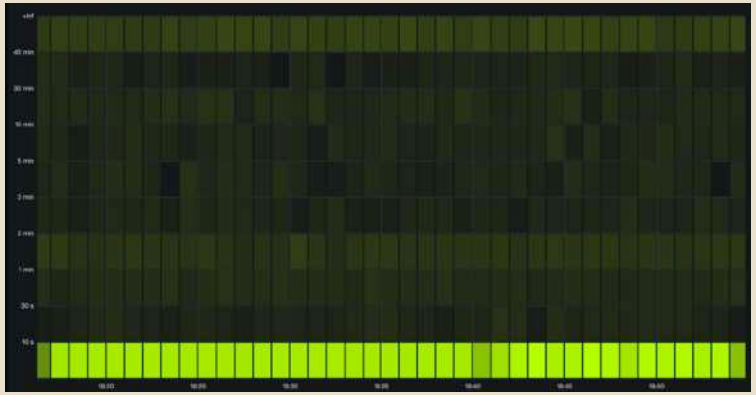
连接队列

- tcp_abort_on_overflow
  - equal 0 (default)
    - 半连接队列满了 ?
      - 忽略客户端syn, 服务端不做任何反应
      - 客户端不断重试发syn, 一直到 tcp_syn_retries = 5
    - 全连接队列满了 ?
      - 忽略客户端ack, 服务端设立定时器发送syn/ack
      - 一直到 tcp_synack_retries = 5
  - equal 1
    - retrun rst

connection reset by peer
&
connection refused

```
$ netstat  -s | egrep "overflowed|ignored"

# 全连接
820481 times the listen queue of a socket overflowed

# 半连接
820481 SYNs to LISTEN sockets ignored
```

移动网络



* 什么是弱网络（通常说的是 移动网络）
  * 总是断连接
  * 总是虚连接
  * 带宽大小不稳
  * 时延不稳定

* 手机移动网络什么时候更换IP？
  * 手动关闭移动网络
  * 开关飞行模式
  * 去了其他大城区和跨市
  * 触发了 IP TTL 的时间，自测在 一天半左右

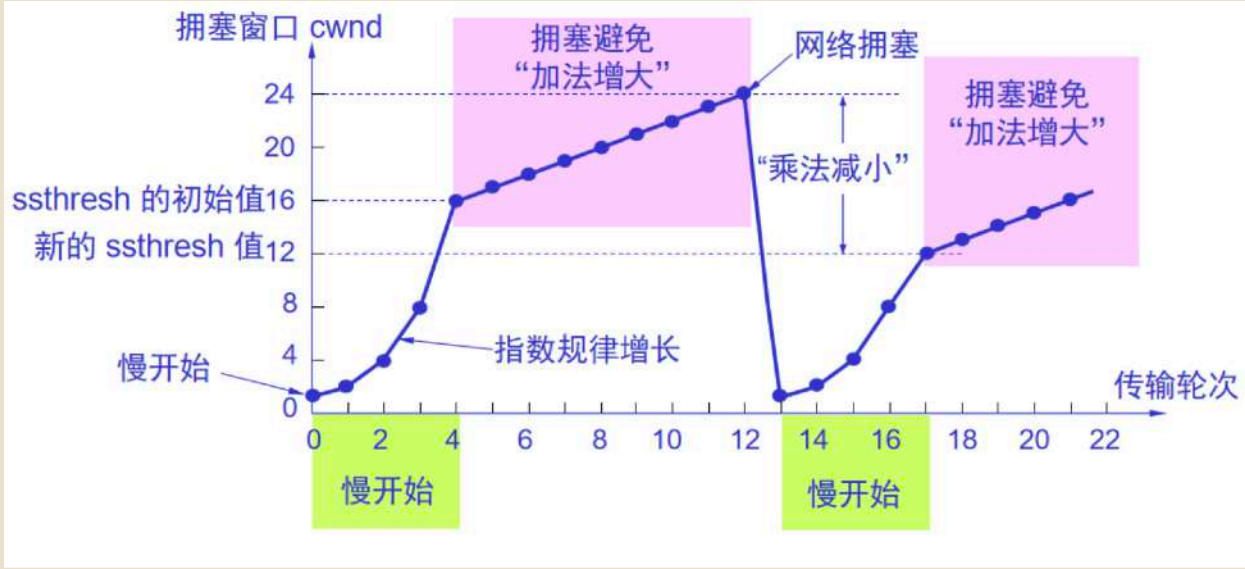
IP 不会因为高速行驶中频繁切换 IP !!!

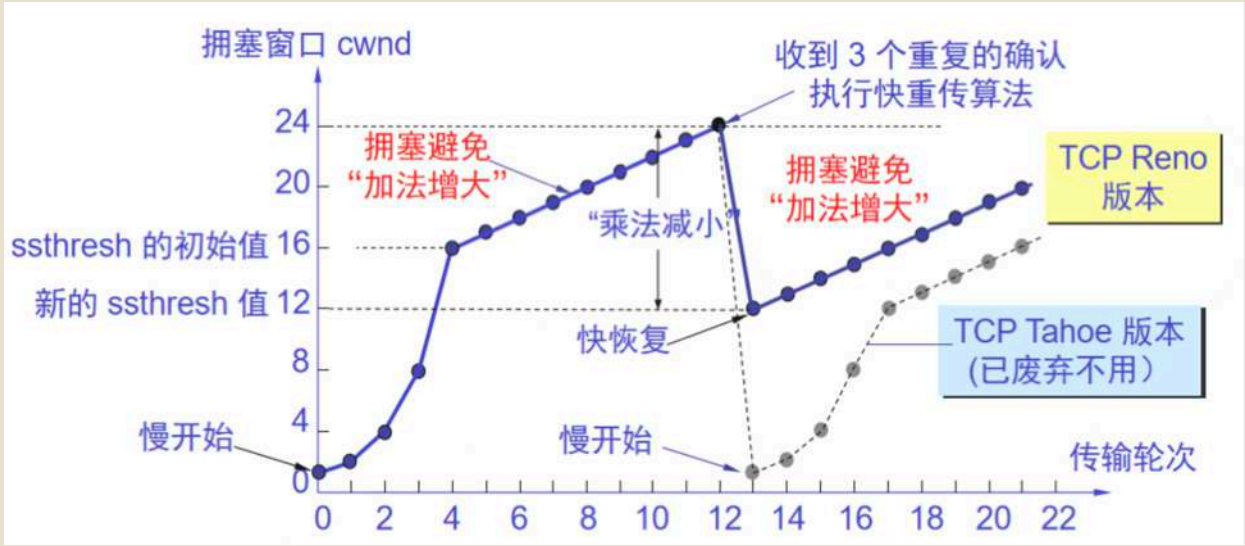
为什么会使用可靠性 udp !!!

* 低延迟
* 低延迟
* 低延迟

拥塞控制

- 慢启动
  - 每收到一个ack, cwnd = cwnd +1
  - 每一轮RTT, cwnd = cwnd x 2
- 拥塞避免
  - cwnd > ssthresh使用拥塞避免算法
  - 每一轮RTT, cwnd = cwnd + 1
- 拥塞发生
  - 超时重传
    - threhold = cwnd/2 , cwnd = 1
    - 进入慢启动阶段
  - 快速重传
    - cwnd = cwnd /2, threhold = cwnd
    - 进入快速恢复
- 快速恢复
  - cwnd = threhold + 3 MSS





kcp

* 基于udp实现的快速可靠传输协议 ！！！
* 更加激进贪婪，牺牲网络的公平性
* 特点
  * 比 TCP浪费10%-20%的带宽的代价
  * 换取平均延迟降低 30%-40%
  * 且最大延迟降低三倍的传输效果 !!!

github.com/skywind3000/kcp

使用udp实现可靠性协议

* 相比tcp
  * 无需三次握手和四次挥手
  * RTO不翻倍，只做 1.5 倍
  * 真正的选择性重传
  * 快速重传 （ 收到2个重复ack ）
  * FEC （Reed-Solomon纠删码）
  * 多路复用
  * ...

连接端口限制？

- 常见的限制
  - 文件描述符限制 (ulimit)
  - 内存限制 (buffer/cache)
  - other sysctl.conf
- 服务端
  - 排除限制条件下，连接数要看tcp 4 元祖
  - client的ip数量最大为2的32次方，port为2的16次方
  - 所以单机理论是大约可到2的48次方
- 客户端
  - 排除限制条件下，连接数要看tcp 4 元祖
  - ip_local_port_range (default 32768 - 60999)

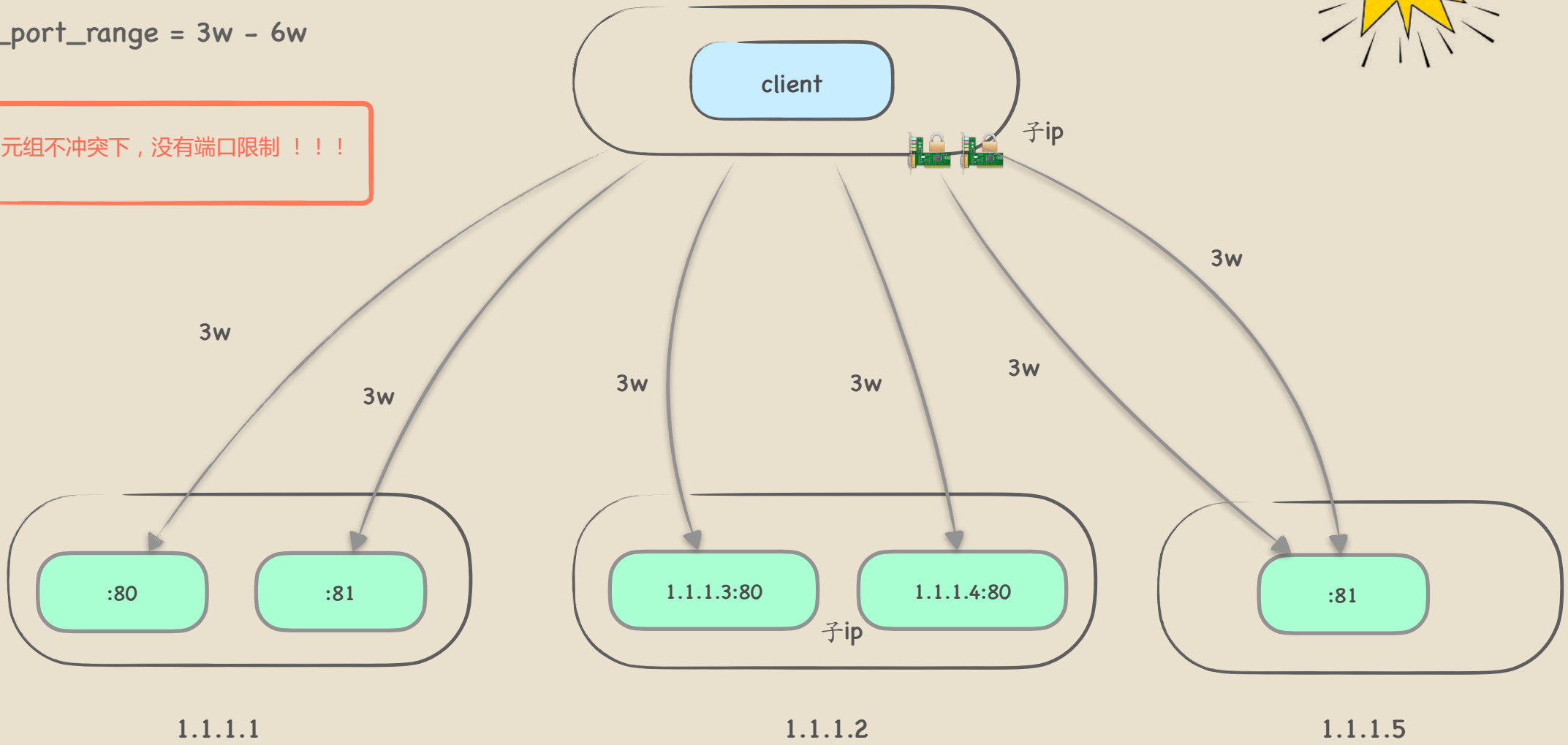
```
$ ss -ant|grep -v :22|grep 34006
ESTAB      0      0      192.168.124.10:34006              111.206.176.91:80
ESTAB      0      0      192.168.124.10:34006              220.194.111.148:80
ESTAB      0      0      192.168.124.10:34006              123.126.104.68:80
ESTAB      0      0      192.168.124.10:34006              220.194.111.149:80
ESTAB      0      0      192.168.124.10:34006              115.159.231.124:80
ESTAB      0      0      192.168.124.10:34006              61.182.138.3:80
ESTAB      263120 0      192.168.124.10:34006              123.125.114.5:80
```

客户端在四元组不冲突下，没有端口限制 ！！！

连接端口限制？

ip_local_port_range = 3w - 6w

客户端在四元组不冲突下，没有端口限制 ！！！



when process crash ?

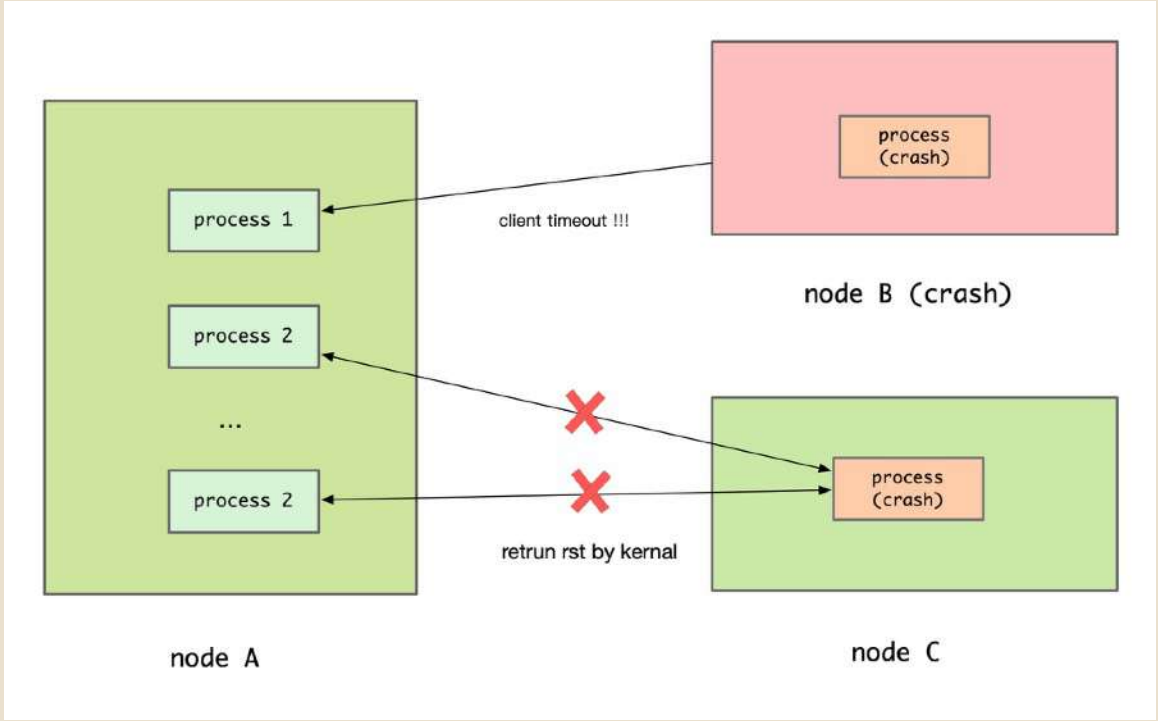
- 当进程退出后，由操作系统内核来收尾 ...
  - 无未读缓冲
    - 内核接管并主动发起 fin
  - 有未读缓冲
    - 触发 rst
  - linger
    - 触发 rst

- FIN
  - init 0 (关机)
  - kill -15 pid
  - kill -9 pid
  - OOM without recv-q

内核帮你搞定 !!!

when server crash ?

- 为什么在curl时 ...
  - 有时会阻塞很久才失败？
  - 有时立马就返回失败？



when router crash ?

两端如何感知连接已关闭 ？

tcp的各状态超时或逻辑心跳 !!!

buffer

- 尽量不要对 socket 指定 SO_SNDBUF, SO_RCVBUF 缓冲区
- linux 下默认对读写缓冲区大小自动调节
- 自动根据 BDP 带宽时延乘积 BDP=rtt*(带宽/8) 优化缓冲区

```
$ > sudo sysctl -a | egrep "rmem|wmem|moderate"

net.ipv4.tcp_moderate_rcvbuf = 1                // 开启接收缓冲区自动调节
net.ipv4.tcp_rmem = 4096    87380   6291456     // 最小值   默认值   最大值
net.ipv4.tcp_wmem = 4096    16384   4194304     // 最小值   默认值   最大值
```

grace upgrade

- 创建进程
  - fork
  - exec
  - system = fork + exec + waitpid
- 只要不指定 close-on-exec flag, 那么子进程就继承文件描述符表 !!!


```c
#include <stdio.h>
#include <sys/types.h>
#include <sys/stat.h>
#include <fcntl.h>
#include <unistd.h>
#include <string.h>
#include <stdlib.h>
#include <unistd.h>
#include <arpa/inet.h>
#include <sys/socket.h>
#include <netinet/in.h>

int main(){
    int serv_sock = socket(AF_INET, SOCK_STREAM, IPPROTO_TCP);
    struct sockaddr_in serv_addr;
    memset(&serv_addr, 0, sizeof(serv_addr));
    serv_addr.sin_family = AF_INET;
    serv_addr.sin_addr.s_addr = inet_addr("127.0.0.1");
    serv_addr.sin_port = htons(1234);
    bind(serv_sock, (struct sockaddr*)&serv_addr, sizeof(serv_addr));
    listen(serv_sock, 20);

    // method 1
    // system("sleep 1111");

    // method 2
    char* arr[] = {"sleep", "1111", NULL};
    execv("/usr/bin/sleep", arr);
    return 0;
}
```

```
[root@host-46 ~ ]$ ps aux|grep -v grep| grep "sleep 1111"
root      393065  0.0  0.0 108052   360 pts/6    S    11:02   0:00 sleep 1111

[root@host-46 ~ ]$ lsof -p 393065 -Pn
COMMAND    PID USER   FD   TYPE    DEVICE  SIZE/OFF       NODE NAME
sleep   393065 root  cwd    DIR       8,2      4096    2564288 /root/test
sleep   393065 root  rtd    DIR       8,2      4096         64 /
sleep   393065 root  txt    REG       8,2     33128 3221227973 /usr/bin/sleep
...
sleep   393065 root   3u    IPv4 409765637       0t0        TCP *:1234 (LISTEN)
```

grace upgrade

send signal usr2

/bin/server_v1

/bin/server_v2

fork-exec with listenFD by dup2

* watch "quit" sig
* add timeout event

so_reuseaddr so_reuseport

load listenfd bind & listen

send signal quit

grace shutdown

epoll_wait

kill connections when trigger timeout !

* 传递 listenfd
  * nginx & golang by dup
  * envoy by uds

if don't recv quit signal for a long time,
send kill !

force exit

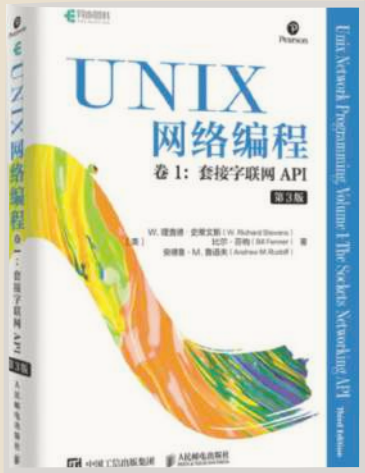
```go
func (g *grace) run() (err error) {
    if _, ok := syscall.Getenv(strings.Split(graceEnv, "=")[0]); ok {
        f := os.NewFile(3, "")
        if g.listener, err = net.FileListener(f); err != nil {
            return
        }
    } else {
        if g.listener, err = net.Listen("tcp", g.srv.Addr); err != nil {
            return
        }
    }

    terminate := make(chan error)
    go func() {
        if err := g.srv.Serve(g.listener); err != nil {
            terminate <- err
        }
    }()

    quit := make(chan os.Signal)
    signal.Notify(quit)

    for {
        select {
        case s := <-quit:
            switch s {
            case syscall.SIGINT, syscall.SIGTERM:
                signal.Stop(quit)
                return g.stop().err

            case syscall.SIGUSR2:
                return g.reload().stop().err
            }

        case err = <-terminate:
            return
        }
    }
}

...

func ListenAndServe(addr string, handler http.Handler) error {
    return WithTimeout(defaultTimeout).ListenAndServe(addr, handler)
}
```

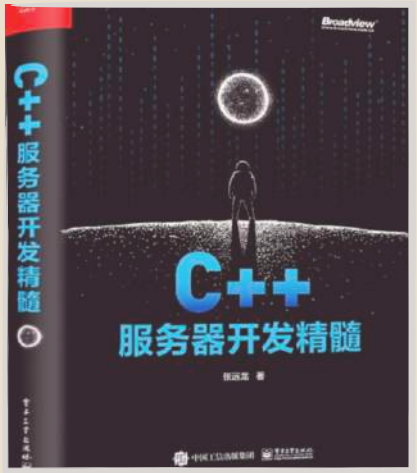
```go
const (
    graceEnv       = "go_http_reload=true" // env flag for reload
)

func (g *grace) reload() *grace {
    f, err := g.listener.(*net.TCPListener).File()
    if err != nil {
        g.err = err
        return g
    }
    defer f.Close()

    var args []string
    if len(os.Args) > 1 {
        args = append(args, os.Args[1:]...)
    }
    cmd := exec.Command(os.Args[0], args...)
    cmd.Stdout = os.Stdout
    cmd.Stderr = os.Stderr
    cmd.Env = append(os.Environ(), graceEnv)
    cmd.ExtraFiles = []*os.File{f}

    g.err = cmd.Start()
    return g
}

func (g *grace) stop() *grace {
    if g.err != nil {
        return g
    }

    ctx, cancel := context.WithTimeout(context.Background(), g.timeout)
    defer cancel()

    if err := g.srv.Shutdown(ctx); err != nil {
        g.err = err
    }

    return g
}
```

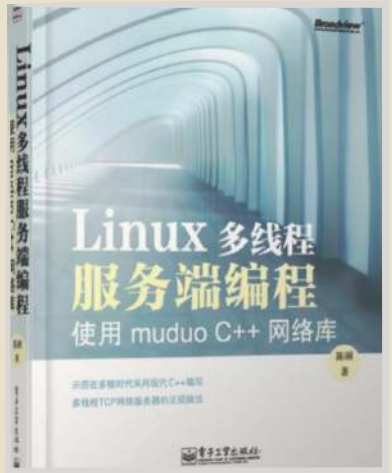
tips

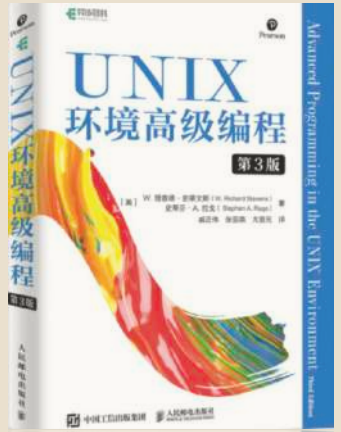
- A 向 B 发送5个包数据，但后面包先到达是否影响socket读取？
  - 内核会实现包的 ofo 排序，交付给应用层的包必然是有序的.
- 不要多线程同时读写socket，虽然不会重复读，覆盖写，但会引发业务读写混乱
- dpdk, sendfile, splice

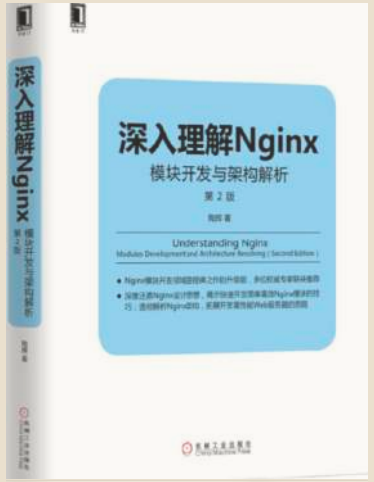
refer





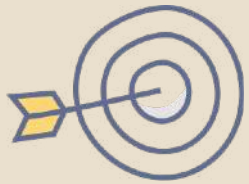






感谢开发内功修炼

@张彦飞



Q & A

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