# Porting a Network Cryptographic Service to the RMC2000: A Case Study in Embedded Software Development

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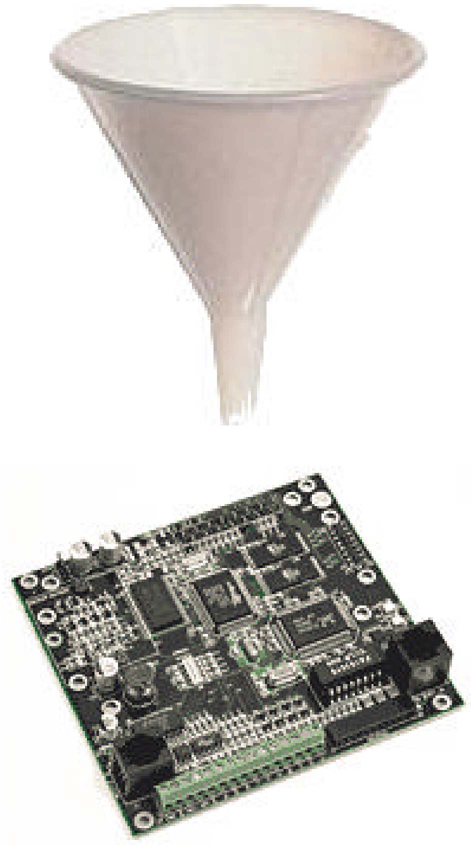
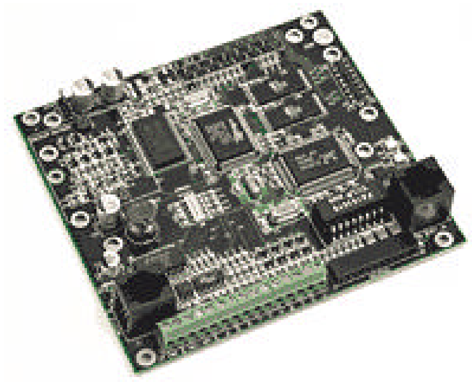
# Porting iSSL to an Embedded Board

iSSL



# Reengineering iSSL for Embedded

iSSL



# iSSL

Transport layer security protocol

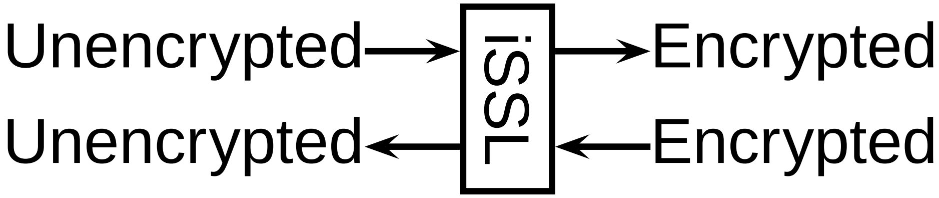
Layers on top of TCP/IP to secure communications

Computationally intensive

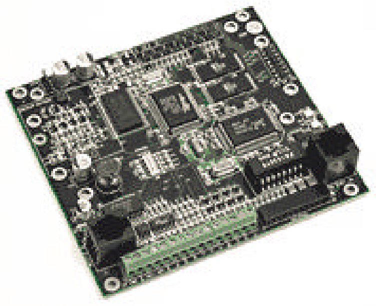
Perfect for a coprocessor: really just a filter

Written for Unix workstations

- Berkeley sockets
- fork
- bignum library



# The RMC2000



8-bit Z80-derived Rabbit 2000 microcontroller @ 30 MHz

512K flash

128K SRAM

64K address space; accesses 1M using bank-switching

10Base-T network interface

Dynamic C development environment

Source for TCP/IP, UDP, and ICMP included

Cheap development kit

# Issues

## Different APIs

- Rabbit’s TCP/IP vs. sockets
- Process model (coroutines vs. fork)
- Interrupts (manual vs. signals)

## Missing APIs

- Filesystem
- Arbitrary-precision integer package

Efficiency

- Assembly vs. C implementation of AES cipher

# Dynamic C

Development environment supplied by Rabbit

C-like language (ANSI minus many features plus others)

# Dynamic C’s Inline Assembly

```
#asm nodebug
InitValues::
   ld hl,0xa0;
c  start_time = 0;   // Inline C
c  counter = 256;    // Inline C
   ret
#endasm
```

Used in error-handling routines that catch hardware and software exceptions.

# Concurrency through Coroutines

```
for (;;) {
  costate {
    waitfor( tcp_packet_port_21() );
    // handle FTP connection
    yield();  // Force context switch
  }
  costate {
    waitfor( tcp_packet_port_23() );
    // handle telnet connection
  }
}
```

We used this to handle multiple network connections.

# New storage classes

```
shared float a, b, c; // Interrupts disabled during access
main() {
   protected int state1; // Battery-backed
   ...
   _sysIfSoftReset() // restore protected variables
}

root int func1() { ... } // in root memory
#memmap root // in root memory
#asm root
 ...
#endasm

xmem int func2() { ... } // in extended memory
```

# API Differences: Networking

```c
int echo_server() {
  int sock, newsock, len;
  struct sockaddr_in addr;
  char buf[LEN];

  if ((sock = socket(AF_INET, SOCK_STREAM, 0)) < 0)
    return -1;

  memset(&addr, 0, sizeof(addr));
  addr.sin_family      = AF_INET;
  addr.sin_addr.s_addr = htonl(INADDR_ANY);
  addr.sin_port        = htons(MYPORT);
  if ( bind(sock, (struct sockaddr *) &addr,
            sizeof(struct sockaddr_in)) < 0 ) return -1;
  if ( listen(sock, LISTENQ) < 0 ) return -1;
  for (;;) {
    if ((newsock = accept(sock, NULL, NULL) ) < 0 )
      return -1;
    if ((len = recv(newsock, buf, LEN, 0)) < 0)
      return -1;
    if (send(newsock, buf, len, 0) < 0) return -1;
    close(conn_s);
  }
}
```

Berkeley Sockets (Original)

```c
int echo_server()
{
  tcp_Socket sock;
  int status;
  char buf[LEN];

  sock_init();
  for (;;) {
    tcp_listen(&sock, PORT, 0, 0, NULL, 0);
    sock_wait_established(&sock, 0, NULL, &status);
    sock_mode(&sock, TCP_MODE_ASCII);
    while (tcp_tick(&sock)) {
      sock_wait_input(&sock, 0, NULL, &status);
      if (sock_gets(&sock, buf, LEN))
        sock_puts(&sock, buf);
    }
  }
}
```

Dynamic C API

# API Differences: Concurrency

```
listen(listen_fd)
for (;;) {
  accept_fd = accept(listen_fd);
  if ((childpid = fork()) == 0) {
    // process request on accept_fd
    exit(0);  // terminate process
  }
}
```

Sockets + Fork

```
for (;;) {
  costate {
    tcp_listen(socket1,TLS_PORT, ...);
    while (sock_established(socket1) == 0) yield;
    // handle request
  }
  costate {
    tcp_listen(socket2,TLS_PORT, ...);
    while((0 == sock_established(socket2))) yield;
    // handle request
  }
  costate {
    tcp_listen(socket2,TLS_PORT, ...);
    while((0 == sock_established(socket2))) yield;
    // handle request
  }
  costate {
        // drive TCP stack
        tcp_tick(NULL);
  }
}
```

Custom + costate

# Missing APIs

- iSSL used a filesystem for optional logging

  We removed support for logging

- RSA cipher uses arbitrary-precision “bignum” library

  We omitted RSA and only ported AES (Rijndael)

- No **`malloc()`** or **`free()`**

  Replacements work very differently; changed program to use statically-allocated memory. Changed to fixed key and block sizes.

- No **`random()`** in Dynamic C libraries

  Wrote a new implementation

# Performance Experiments

Compared ported implementation of AES cipher with Rabbit-supplied hand-optimized assembly.

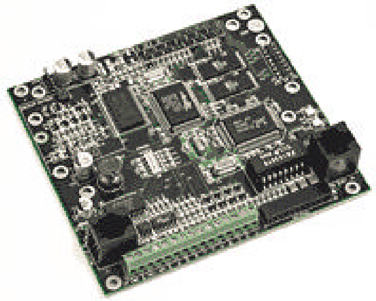
Found assembly was 15–20× faster

Tried hand-optimizing C (moved data to “root” memory, unrolled loops, etc.); only 20% improvement

Code size fairly good: assembly only 9% smaller

# Conclusions

Ported iSSL to an RMC2000 development board



Biggest challenges from different APIs

Missing APIs also a problem

Performance disappointing: assembly implementation of AES cipher 15–20× faster

Bottom line: look carefully at what assumptions a program makes about its environment before porting it.

Future work: Dealing with different APIs.

Synthesizing wrappers? Code reengineering tool?