“Hacking cash machines”

Extracting 3DES Keys from an IBM 4758 running CCA software

(or, “Why I was wearing a tie on the telly”)

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Summary

- Keys and Ciphers
- The IBM 4758 Cryptoprocessor
- How PIN values work
- Mike Bond’s “API attacks”
- The low-cost hardware “DES cracker”
- How to extract 3DES keys from a IBM 4758
- Some thoughts on “full disclosure”

Keys and ciphers

- Kerckhoff's doctrine (1883)
  - the security of a system should depend upon its key and not upon its design remaining obscure
- If there is no shortcut then the security of a system depends upon its key length
  - trying all possibilities @ 33 million keys/sec
    - 2^{40} = 9 hours
    - 2^{56} = 68.4 years
    - 2^{80} = 5 billion years

A History of Tamper Resistance

Problem: another program on the same machine can access your sensitive data

- Put keys into separate microprocessor
- Put microprocessor into a tin box
- Photocells and tilt detection
- Epoxy “potting”
- Tamper detecting barriers

The IBM 4758

- Protective barrier with wires of chemically similar compound
- Detectors for temperature & X-Rays
- “Tempest” shielding for RF emission
- Low pass filters on power supply rails
- Multi-stage “ratchet” boot sequence

= STATE OF THE ART PROTECTION!


CAUTION
VARTA
Lithium 3V

CCA and PIN values

- Common Cryptographic Architecture
  - runs on many IBM platforms
  - available for free to run on a 4758
- A PIN value (in the CCA world) is the account number encrypted with (112 bit) 3DES key and last few bytes made decimal
- Changing a PIN => changing an offset

Key Entry under CCA

- Each key is loaded in two parts, which are then XORed together
  - XOR means that knowing one part tells you NOTHING about the final key value
- Two security officers, “trusted” not to collude, are given one part of the key each.
  - they authenticate themselves and then separately load these into the 4758.
- This makes the key entirely secure...

Michael Bond’s “API attacks”

- New type of attack: use standard API in non-standard way to cause dumb things
  - Overloaded key types
  - Unauthorised type casting
  - 3DES binding attack
  - Related keys

Mike’s PhD topic targets formal methods that will detect (and avoid) these problems

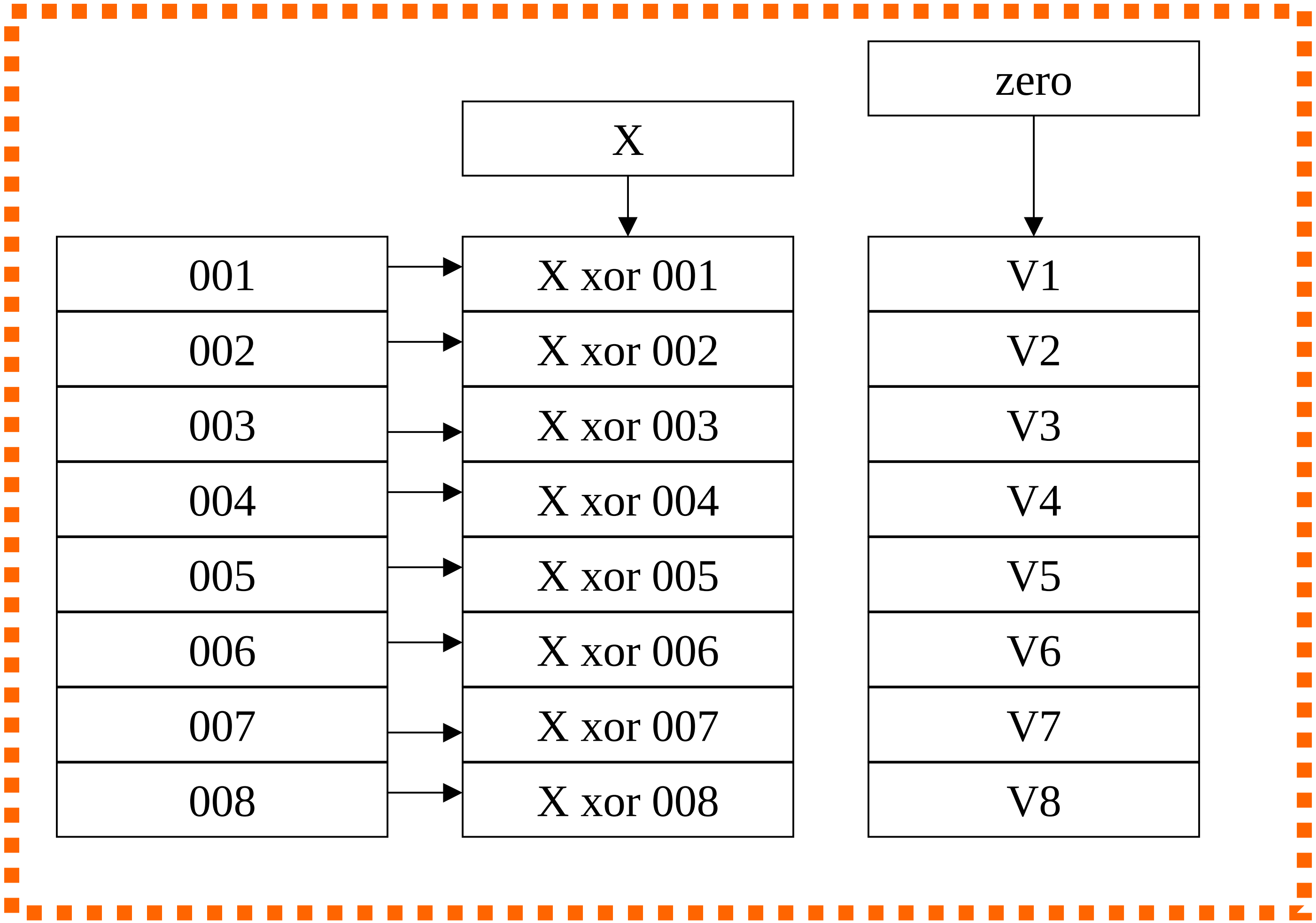
The Meet-in-the-Middle Attack

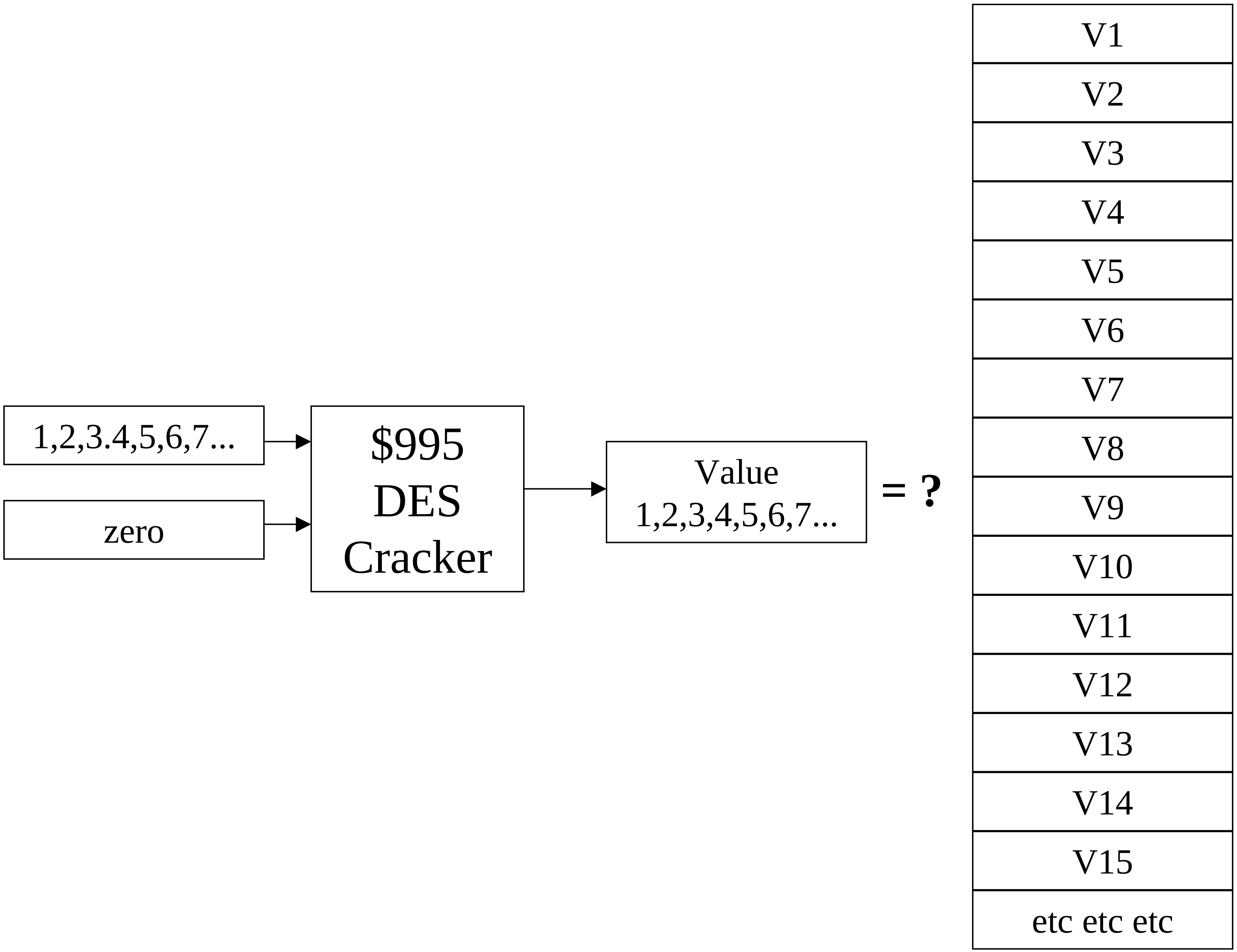
Idea: Attack multiple keys in parallel

- Encrypt the same plaintext under each of the multiple keys to get a "test vector"
- Attack by trying all keys in sequence but check for a match against any test vector value (check is faster than encrypt)
- Typical case: A 2^{56} search for one key becomes a 2^{42} search for 2^{14} keys

Attacking the CCA : Part 1

- Create unknown DES key part
- XOR in “...001”, “...002”, “...003” etc
- Encrypt zero value under each key
- Repeat to get 16384 (2^{14}) results
- Some complexity because of parity issues, but essentially simple & takes 10 minutes.
- Use “brute-force” attack to get the DES key

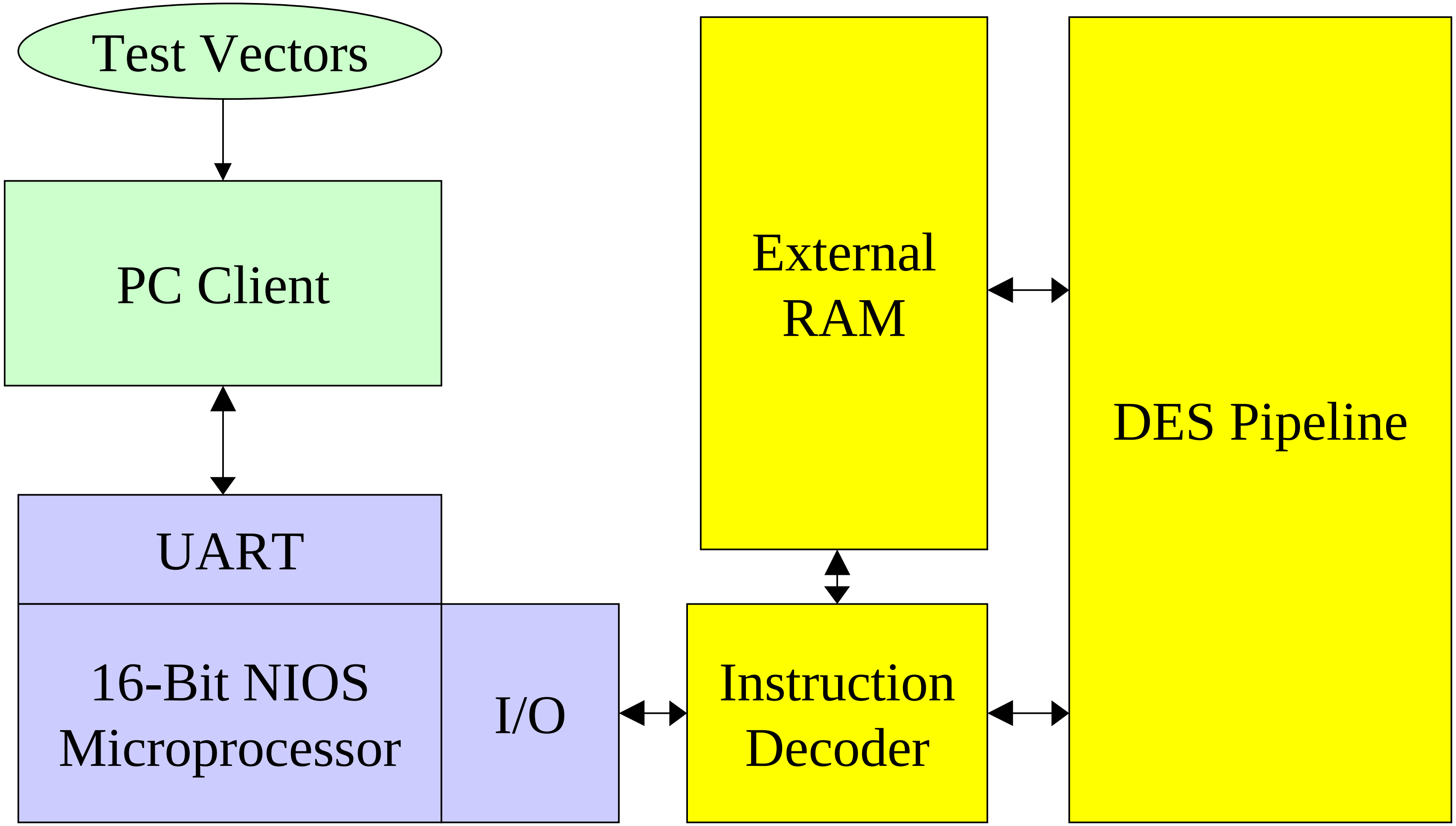

X
zero
001
002
003
004
005
006
007
008
X xor 001
X xor 002
X xor 003
X xor 004
X xor 005
X xor 006
X xor 007
X xor 008
V1
V2
V3
V4
V5
V6
V7
V8


1,2,3.4,5,6,7...
zero
$995
DES
Cracker
Value
1,2,3,4,5,6,7...
= ?
V1
V2
V3
V4
V5
V6
V7
V8
V9
V10
V11
V12
V13
V14
V15
etc etc etc

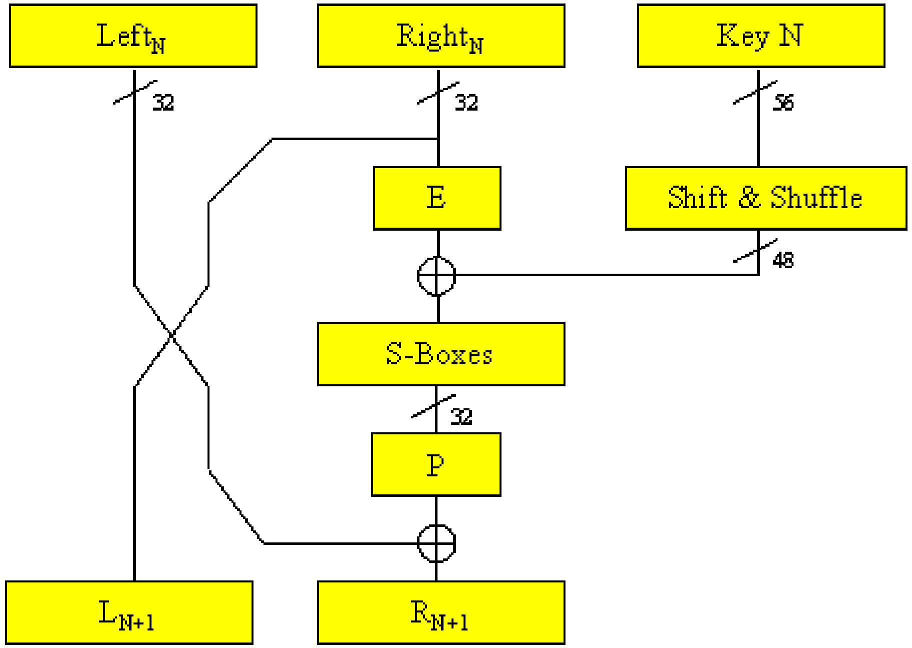
Low-cost DES Cracker

- \$995 Excalibur kit (Altera 20K200 FPGA)
  - chip cost is ~\$5 (in volume; \$178 one-off)
- 33MHz pipeline (& 60MHz possible)
- this is ~2^{25} keys/second
  - 56 bit DES = 68 years
- However... it looks for 16384 keys in parallel
  - with average luck, find first key in 25.4 hours

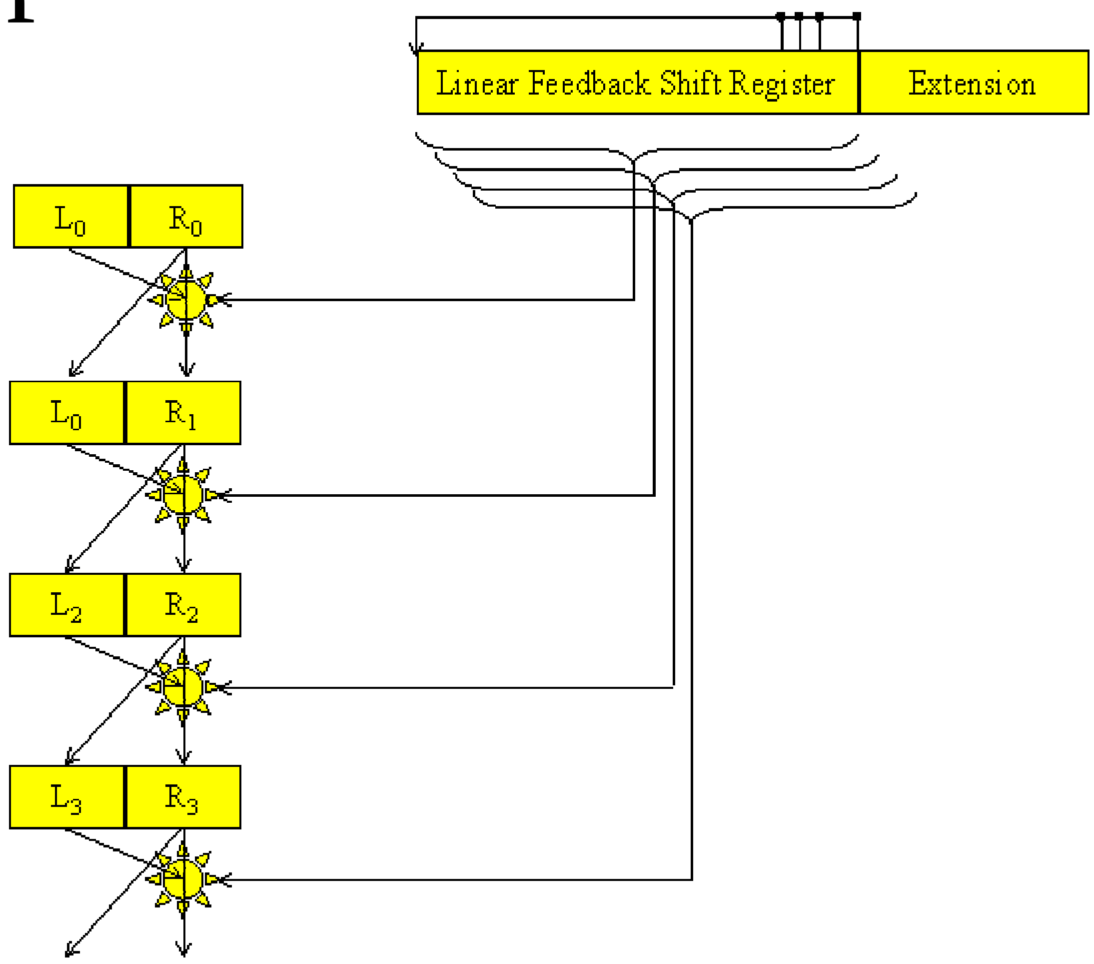
Design Overview



A DES Pipeline Stage



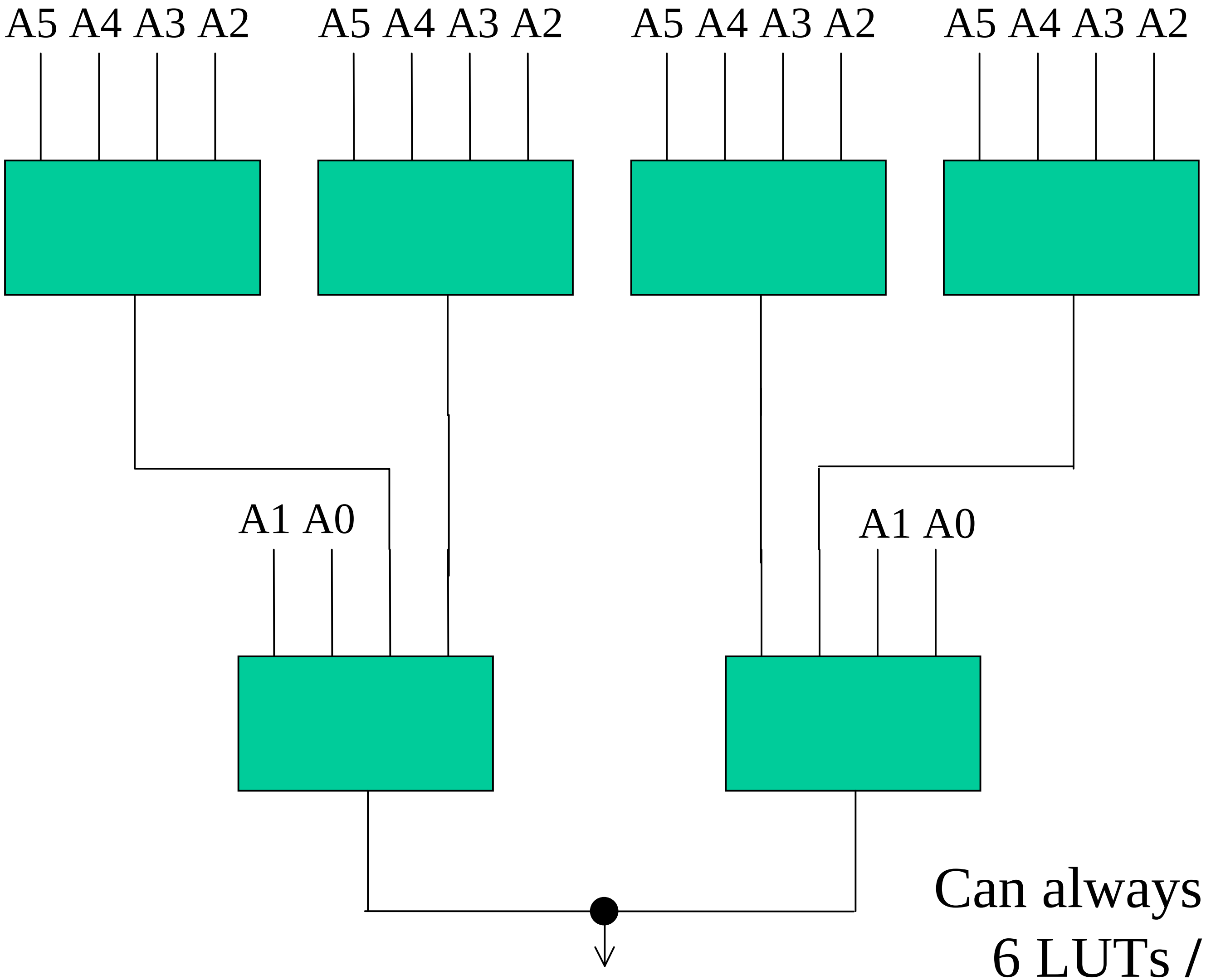
DES Pipeline



Fitting the Design Onto the Chip

Max of 8320 LUTs … and using all except 17

- LFSR saves pipelining key values
- Careful attention to instruction decoder
- Minimal settings for NIOS processor
- Redesigned S-Boxes



Can always achieve:
6 LUTs / bit
=> 24 LUTs/S-Box

Some S-Boxes Have Structure

- SBOX4 : address : 543210 : 4 bit result =

7, 13, 14, 3, 0, 6, 9, 10, 1, 2, 8, 5, 11, 12, 4, 15,
13, 8, 11, 5, 6, 15, 0, 3, 4, 7, 2, 12, 1, 10, 14, 9,
10, 6, 9, 0, 12, 11, 7, 13, 15, 1, 3, 14, 5, 2, 8, 4,
3, 15, 0, 6, 10, 1, 13, 8, 9, 4, 5, 11, 12, 7, 2, 14.

- Rearrange addressing in order 532104

7, 14, 0, 9, 1, 8, 11, 4, 10, 9, 12, 7, 15, 3, 5, 8,
13, 11, **6**, 0, 4, 2, 1, 14, 3, **0**, 10, **13**, 9, 5, 12, 2,
13, 3, **6**, 10, 2, 5, 12, 15, 6, **0**, 11, **13**, 1, 14, 2, 4,
8, 5, 15, 3, 7, 12, 10, 9, 15, 6, 1, 8, 4, 11, 7, 14.

and then feed it into the logic minimiser...

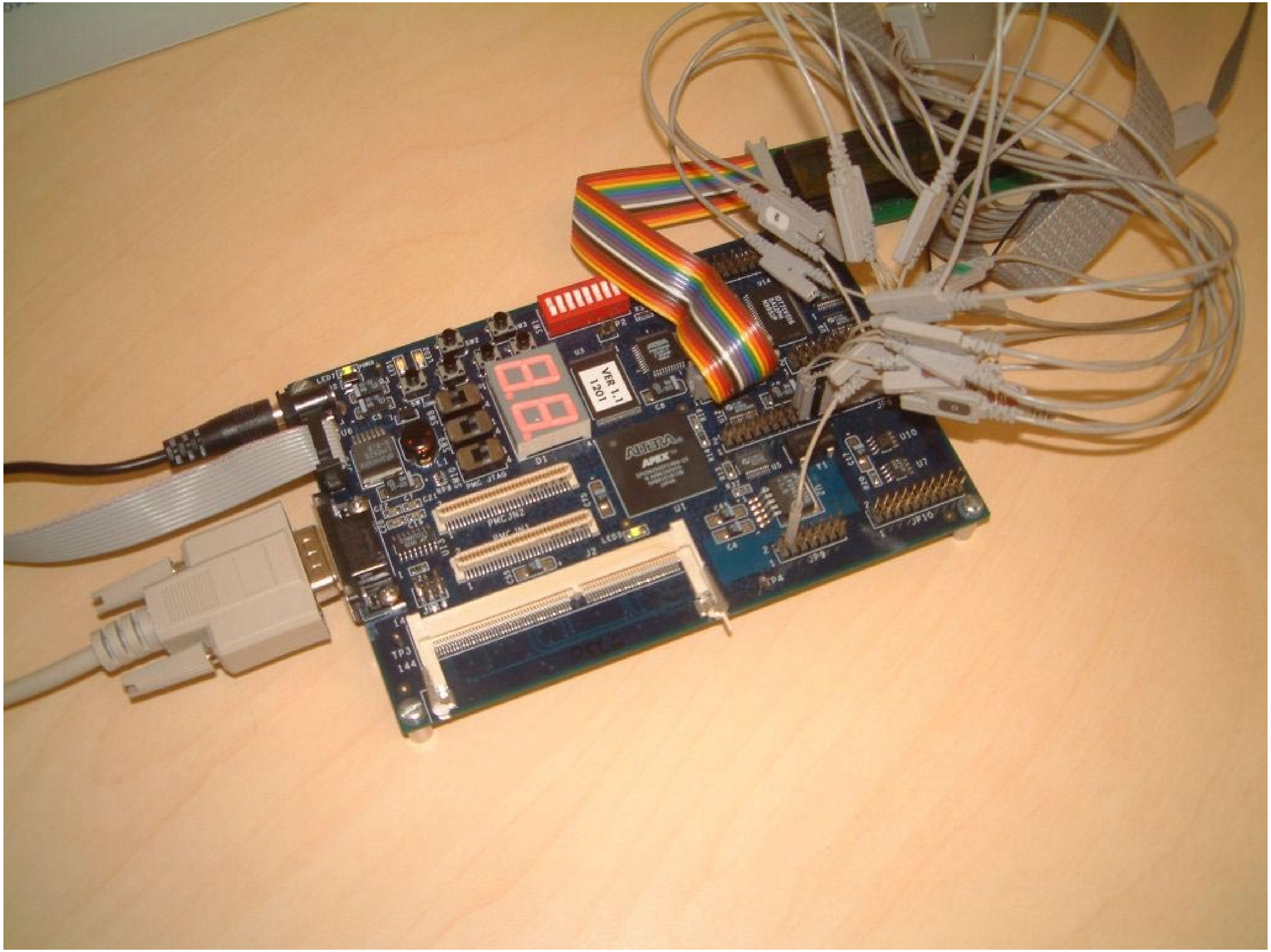
```
X1 = a[4]  & (a[5]  $  a[3] $  a[2])
    # !a[4]  & (a[5] &  a[2] # !a[5] & !a[3] & !a[2]);

X2 = a[4]  & (a[5] & !a[3] # !a[5] &  a[3] & !a[2])
    # !a[4]  & (a[3] $ (!a[2] # !a[5]));

X3 = a[4]  &  a[2] & (a[3] # !a[5])
    # !a[4]  & (a[2] $ (a[5] #  a[3]));

X4 = a[4]  & (a[5] & !a[3] & !a[2] # !a[5] &  a[2])
    # !a[4]  & (a[5] $ !a[3]);

R0 = a[0] # a[1] &  X4 # !a[1] & !X3;
R1 = a[0] # a[1] & !X1 # !a[1] &  X2;

data0 = (a[1] & !X1 # !a[1] & X2 # !a[0]) & R0;
data1 = (a[1] & !X4 # !a[1] & X3 # !a[0]) & R1;
```

ie: SBOX4 uses just 16 LUTs, not 24

savings also on:

SBOX2: 23
SBOX3: 23
SBOX7: 23
SBOX8: 22

total = 13 LUTs
(* 16 stages = 208)


VER 1.1
1201
ALTERA
APEX
PMC JN2
PMC JN1
JTAG
TP3
144

Why Use Hardware Anyway?

Hardware DES implementation is >>25 times faster than the best software implementations.

- eg: Software [seeking any 1 of 64K keys]
  - 6 modern PCs running in parallel
  - £4500
  - 84 hours (3.5 days)
- & Hardware [seeking any 1 of 16K keys]
  - Altera evaluation board (no soldering required)
  - $995
  - 22.5 hours (for same example, NB: 1/4 parallelism)

Attacking the CCA : Part 2

- Recall we had 16K related DES keys
- We can crack one of these in ~1 day
- Now create 16K related 3DES keys with “replicate” halves and “exporter” capability
  - 3DES = EncryptA; DecryptB; EncryptA
- Export the DES key under the 3DES keys
- Since replicate can also crack in ~1 day

Attacking the CCA : Part 3

- Create non-replicate 3DES key by combining two unequal halves with the replicate halves that we’ve now determined
- Export all the CCA keys under this key
- Download list of PIN offsets
- Use magnetic stripe writer to create cards
- Use any ATM to extract money from accounts
- Go to Bermuda!

IBM's Response

- Nov 2000 (Mike's first results)
  - nothing (typecasting seen as legitimate)
- May 2001 (Mike's CHES paper)
  - nothing
- Nov 2001 (Newsnight program)
  - attack "infeasible in realistic system implementations"
  - followed by advice to disable `Combine_Key_Parts`
- Real Soon Now
  - new version of CCA available [+ bug fix]

“Full Disclosure”

- Should you tell vendor & keep quiet ?
  - vendor has limited incentive to act
- Should you publish & be damned ?
  - “black hats” may be unaware of problem
- Should exploits be published ?
  - “script kiddies” & sysadmins both need them
- Current consensus is to tell vendor and publish after pre-set delay. Recent decisions to suppress exploit info are controversial.

Make Your Own!

http://www.cl.cam.ac.uk/~rnc1/descrack/