# Cryptography with Everyday Objects

## Mucking about with cards and stuff

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# Outline

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# Chaum's Dining Cryptographers

**Assumptions:**

- *n* cryptographers in a circle
- 0 or 1 of them paying the bill
- Honest but curious

**Goals:**

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Assumptions/goals:

- Now any number might be paying
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- Coins and Dice: Dining Cryptographers
- Cards: Dating and Unanimity Protocols
  - Bennett's Dating Protocol
  - Extending to Three Players
- Envelopes: Secret Santa Protocols
- Envelopes: Vetoes and Threshold Voting Protocols
- Formal Analysis

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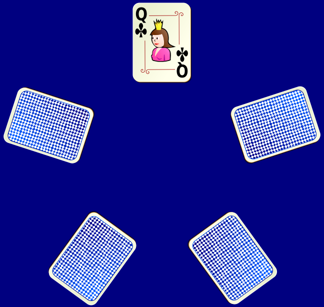

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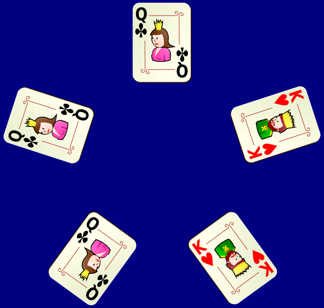

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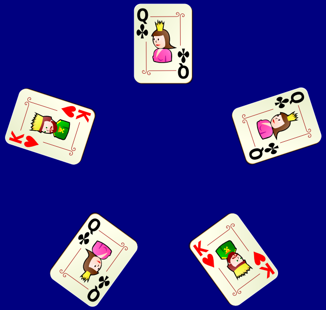

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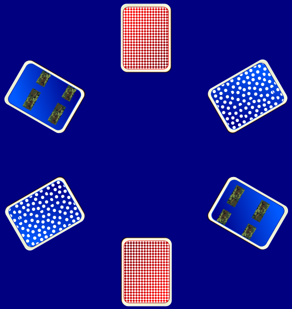

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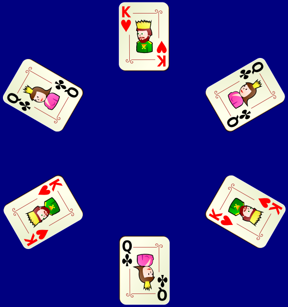

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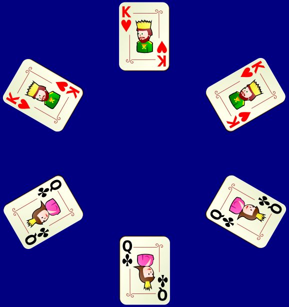

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Cards: Dating and Unanimity Protocols

Envelopes: Secret Santa Protocols
- The Secret Santa Problem
- The Father Cryptmas Protocol
- The Faster Crassmas Protocol

Envelopes: Vetoes and Threshold Voting Protocols

Formal Analysis

# Secret Santa problem

Goals:

- Each person buys a gift for someone else
- Gift mapping should be a derangement or a cycle
- Givers are anonymous; receivers aren't

Ingredients:

- Thick envelopes
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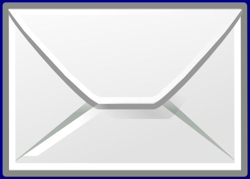
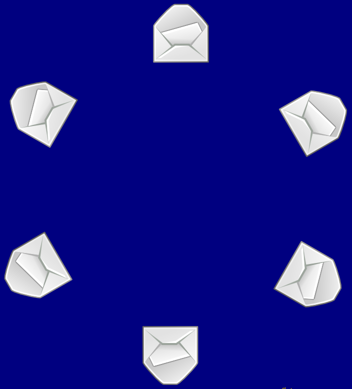


# The Father Cryptmas Protocol: shuffling

Now shuffle and redistribute:

1. Shuffle face down, lay in circle, open flaps
2. Slide cards out, and move them clockwise
3. Seal, shuffle, distribute
4. Open secretly, buy gift for person named on card



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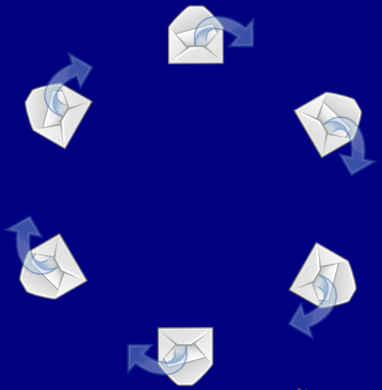

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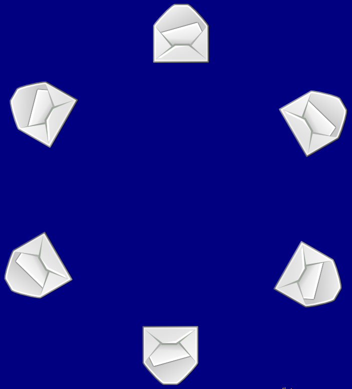

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Each person should:

1. Take an envelope and sign the front
2. Insert a €50 note
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5. Optionally include cards: they move the other way

Advantages:

- Exact parity of presents
- Saves buying the presents

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Goals:

- Each person casts a YES or a NO vote
- Any NO vote vetoes the motion
- We want to reveal only whether the motion was carried

Ingredients:

- Thick envelopes
- Thick card
- Cloth bag

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# Veto Protocol using envelopes

At the end:

- the envelope in the bag is opened
- YES means no veto
- blank means vetoed

Discards must be shuffled or destroyed!

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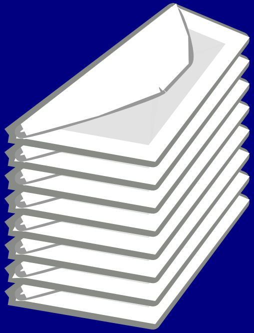
- Coins and Dice: Dining Cryptographers
- Cards: Dating and Unanimity Protocols
- Envelopes: Secret Santa Protocols
- Envelopes: Vetoes and Threshold Voting Protocols
  - Vetoes and thresholds: the problem
  - Veto Protocol
  - Threshold Protocol
- Formal Analysis

# Threshold Protocol using envelopes

Idea:

- Rather than one envelope in the bag:
  - we need a FIFO queue of envelopes
  - to say no: add a NO, pop a YES
  - to say yes: do nothing
  - carried if $\geq k$ YESes popped



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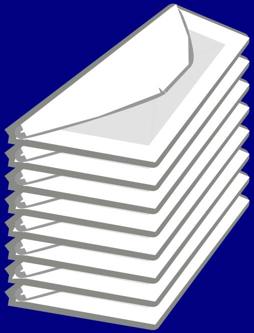

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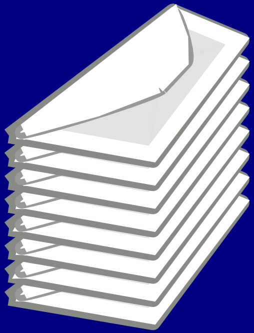

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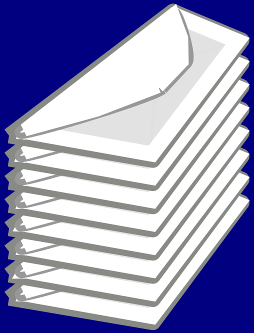

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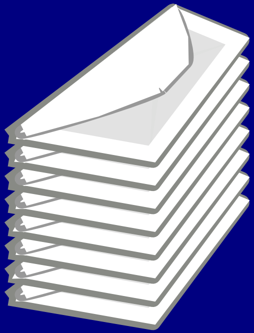

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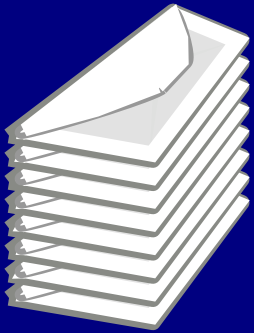

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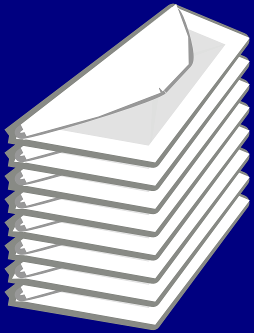

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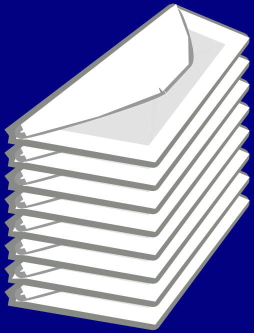

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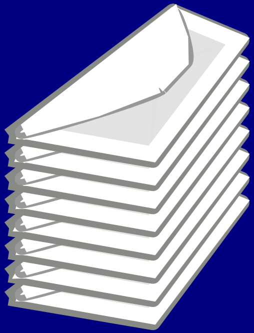

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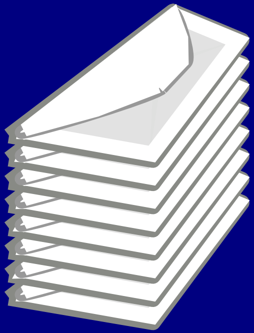

# Threshold Protocol using envelopes

At the end:

- Open the bottom envelope
- It contains the group decision

Discards must be shuffled...

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# Strengthening the Threshold Protocol

Works in honest-but-curious model:

- but not a stronger attacker
- can manipulate the stack

Solution:

- add Velcro tabs to each envelope
- publicly stick envelope to top
- only allowed one ‘rip’ under the table

# Outline

# Modelling the protocols in CSP

We will model the dating protocol and the unanimity protocol in CSP:

- Build some general functions and processes:
  - Process to 'pick the cards up'
  - Function to generate rotations of a sequence
  - Process to announce a rotation non-deterministically
  - Process to allow us to control players' choices (for specification)
- Use them to model each protocol

# Modelling the protocols in CSP

We will model the dating protocol and the unanimity protocol in CSP:

- Build some general functions and processes:
  - Process to ‘pick the cards up’
  - Function to generate rotations of a sequence
  - Process to announce a rotation non-deterministically
  - Process to allow us to control players’ choices (for specification)
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# Collecting cards and announcing a result

$$ANNOUNCE(xs) = ANNOUNCE\_FROM(allrots(xs))$$

$$ANNOUNCE\_FROM(xss) = \bigsqcap_{xs \in xss} announce!xs \rightarrow Stop$$

$$COLLECTING(xs, 0, cur) = rotate \rightarrow ANNOUNCE(xs)$$

$$COLLECTING(xs, rem, cur) =$$

$$place.cur?X \rightarrow COLLECTING(xs \frown \langle X \rangle, rem - 1, cur + 1)$$

# Outline

Coins and Dice: Dining Cryptographers

Cards: Dating and Unanimity Protocols

Envelopes: Secret Santa Protocols

Envelopes: Vetoes and Threshold Voting Protocols

Formal Analysis
- Common Issues
- Dating Protocol
- Unanimity Protocol

# Modelling the dating protocol

$$
\begin{aligned}
P1\_DATE &= accept.1 \rightarrow place.1.Q \rightarrow place.2.K \rightarrow Stop \\
&\quad \square\; veto.1 \rightarrow place.1.K \rightarrow place.2.Q \rightarrow Stop \\
P2\_DATE &= accept.2 \rightarrow place.3.K \rightarrow place.4.Q \rightarrow Stop \\
&\quad \square\; veto.2 \rightarrow place.3.Q \rightarrow place.4.K \rightarrow Stop
\end{aligned}
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Note:

- Players accept or veto, then place cards accordingly
- No cheating allowed: honest-but-curious model

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# Building the system

$$COLLECT\_CARDS\_DATE = COLLECTING(\langle Q \rangle, 4, 1)$$

$$DATE\_SYSTEM = (P1\_DATE \mathbin{|||} P2\_DATE) \underset{\{|place.x | x \in \{1..4\}|\}}{\|} COLLECT\_CARDS\_DATE$$

# Specifying the property

$$P2\_EVENTS = \{|accept.2, veto.2, place.3, place.4|\}$$

$$P1\_DATE\_VIEW(choices) = (DATE\_SYSTEM \underset{\{|accept, veto|\}}{\|} CONTROLS(choices)) \setminus P2\_EVENTS$$

$$P1\_DATE\_VIEW(\langle 0, 0 \rangle) =_T P1\_DATE\_VIEW(\langle 0, 1 \rangle)$$

- Player 2 handled similarly
- FDR confirms specifications hold

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# Modelling the unanimity protocol

Almost exactly the same:

$$\begin{array}{l} \mathit{EXT\_UNANIM\_VIEW}(\mathit{choices}) = \\ \quad (\mathit{UNANIM\_SYSTEM} \underset{\{|\mathit{accept},\mathit{veto}|\}}{\parallel} \mathit{CONTROLS}(\mathit{choices})) \\ \qquad \setminus \{|\mathit{accept}, \mathit{veto}, \mathit{place}|\} \end{array}$$

- From the perspective of an external observer
- Only the final rotated arrangement visible

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# Specifications for the unanimity protocol

$$EXT\_UNANIM\_VIEW(\langle 0,0,0\rangle) =_T EXT\_UNANIM\_VIEW(\langle 1,1,1\rangle)$$

and, whenever $\{a,b,c\} = \{d,e,f\} = \{0,1\}$

$$EXT\_UNANIM\_VIEW(\langle a,b,c\rangle) =_T EXT\_UNANIM\_VIEW(\langle d,e,f\rangle)$$

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$$EXT\_UNANIM\_VIEW(\langle a,b,c\rangle) =_T EXT\_UNANIM\_VIEW(\langle d,e,f\rangle)$$

# Arguing in a circle

```
-- These six checks succeed
assert EXT_UNANIM_VIEW(<0,0,1>) [T= EXT_UNANIM_VIEW(<0,1,0>)
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-- These two checks fail
assert EXT_UNANIM_VIEW(<0,0,0>) [T= EXT_UNANIM_VIEW(<0,0,1>)
assert EXT_UNANIM_VIEW(<0,0,1>) [T= EXT_UNANIM_VIEW(<0,0,0>)
```

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  - Give reasonable security in social contexts
  - Don’t require any crypto or electronics
- Formal analysis of two protocols

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