Peer-to-Peer Networks
13 Security

Christian Schindelhauer
Technical Faculty
Computer-Networks and Telematics
University of Freiburg

Attacks

- Denial-of-Service Attacks (DoS)
  - or distributed denial of service attacks (DDoS)
  - one or many peers ask for a document
  - peers are slowed down or blocked completely
- Sybil Attacks
  - one attacker produces many fake peers under new IP addresses
  - or the attacker controls a bot-net
- Use of protocol weaknesses
- Infiltration by malign peers
  - Byzantine Generals
- Timing attacks
  - messages are slowed down
  - communication line is slowed down
  - a connection between sender and receiver can be established
- Poisoning Attacks
  - provide false information
  - wrong routing tables, wrong index files etc.
- Eclipse Attack
  - attack the environment of a peer
  - disconnect the peer
  - build a fake environment

Solutions to the Sybil Attack

- Survey paper by Levine, Shields, Margonin, 2006
- Trusted certification
  - only approach to completely eleminate Sybil attacks
    - according to Douceur
  - relies on centralized authority
- No solution
  - know the problem and deal with the consequences
- Resource testing
  - real world friends
  - test for real hardware or addresses
    - e.g. heterogeneous IP addresses
  - check for storing ability
- Recurring cost and fees
  - give the peers a periodic task to find out whether there is real hardware behind each peer
    - wasteful use of resources
  - charge each peer a fee to join the network
- Trusted devices
  - use special hardware devices which allow to connect to the network

Solutions to the Sybil Attack

- Survey paper by Levine, Shields, Margonin, 2006

- In Mobile Networks
  - use observations of the mobile node
    - e.g. GPS location, neighbor nodes, etc.
- Auditing
  - perform tests on suspicious nodes
  - or reward a peer who proves that it is not a clone peer
- Reputation Systems
  - assign each peer a reputation which grows over the time with each positive fact
  - the reputation indicates that this peer might behave nice in the future
  - Disadvantage:
    - peers might pretend to behave honestly to increase their reputation and change their behavior in certain situations
    - problem of Byzantine behavior

The Problem of Byzantine Generals

- 3 armies prepare to attack a castle
- They are separated and communicate by messengers
- If one army attacks alone, it loses
- If two armies attack, they win
- If nobody attacks the castle is besieged and they win
- One general is a renegade
  - nobody knows who

The Problem of Byzantine Generals

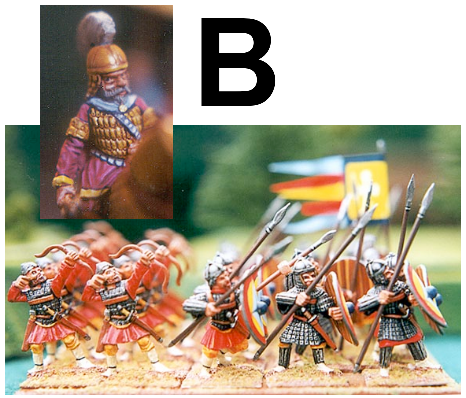
- The evil general X tries
  - to convince A to attack
  - to convince B to wait
- A tells B about X‘s command
- B tells B about his version of X‘s command
  - contradiction
- But is A, B, or X lying?

A

Attack!

X

B

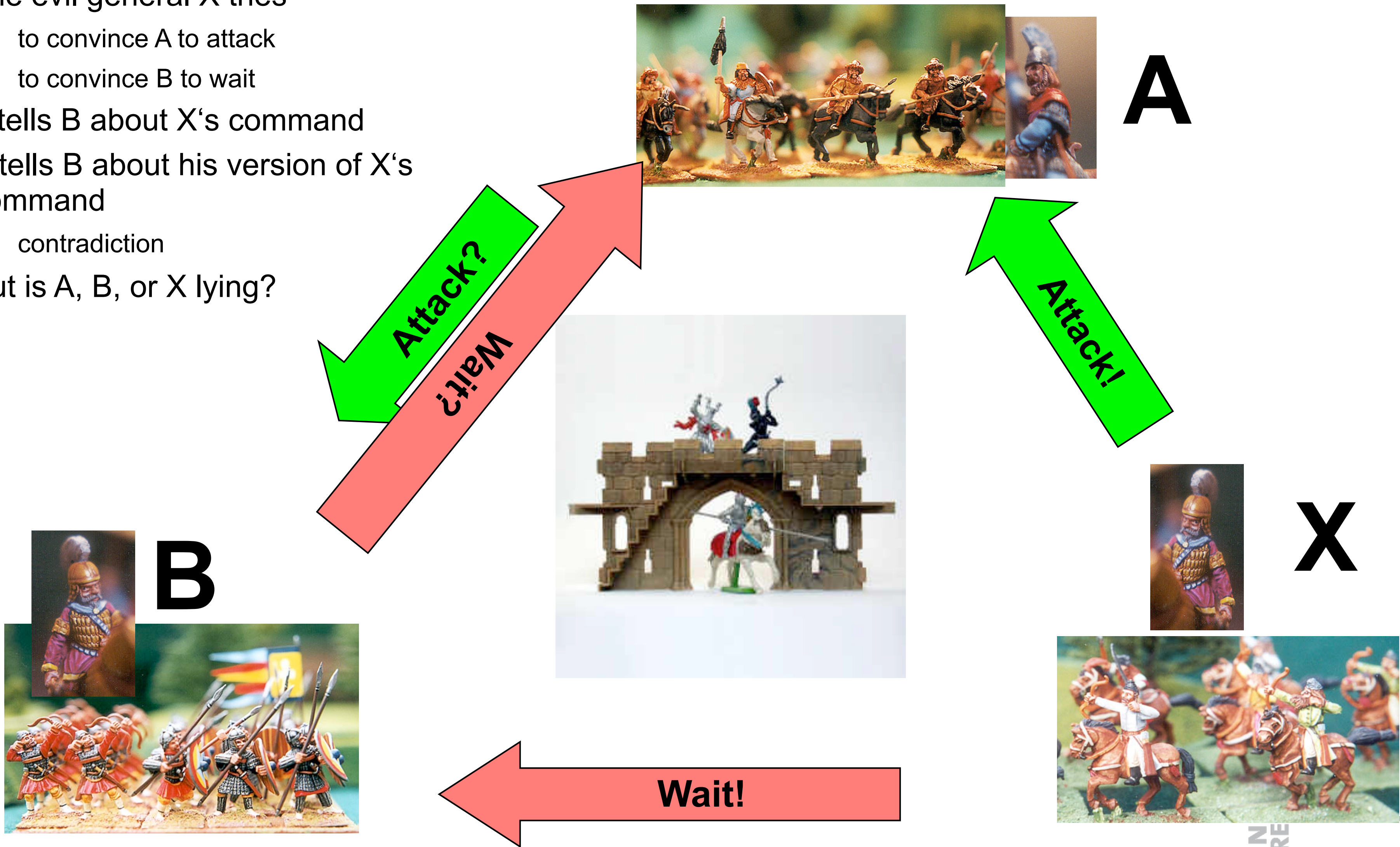


Wait!

The Problem of Byzantine Generals

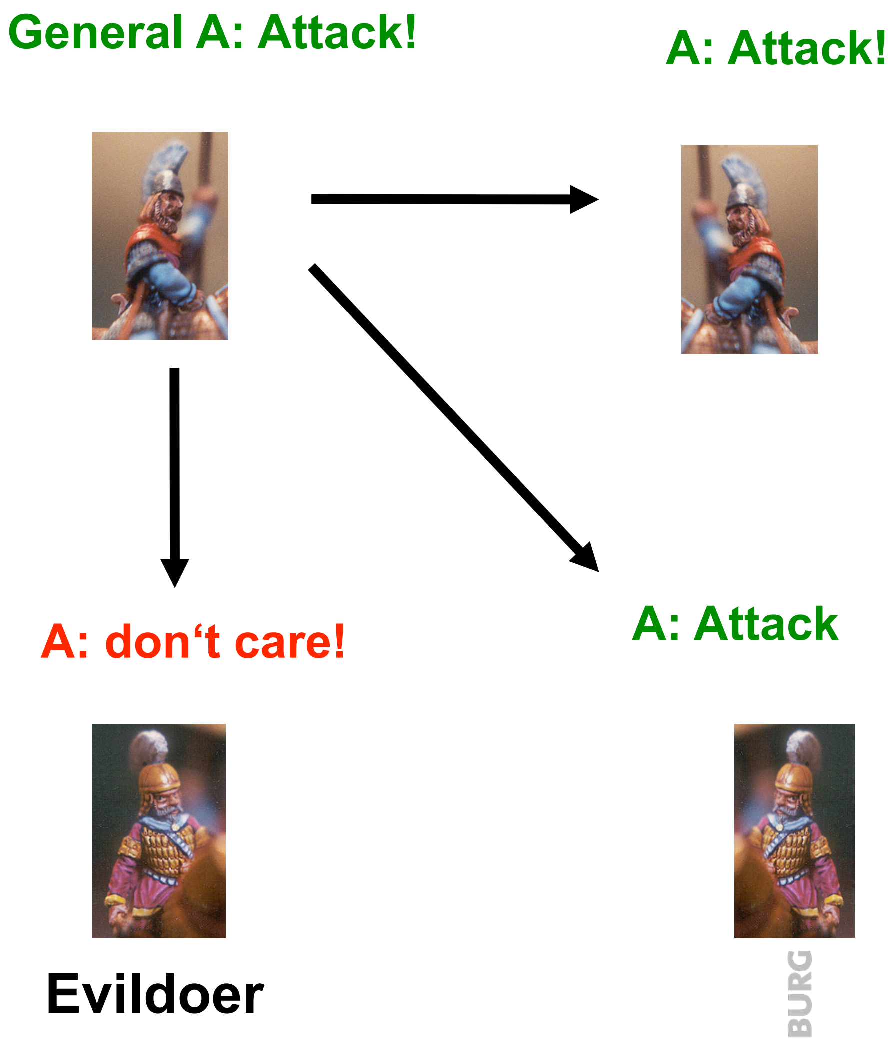
CoNe Freiburg

- The evil general X tries
  - to convince A to attack
  - to convince B to wait
- A tells B about X‘s command
- B tells B about his version of X‘s command
  - contradiction
- But is A, B, or X lying?



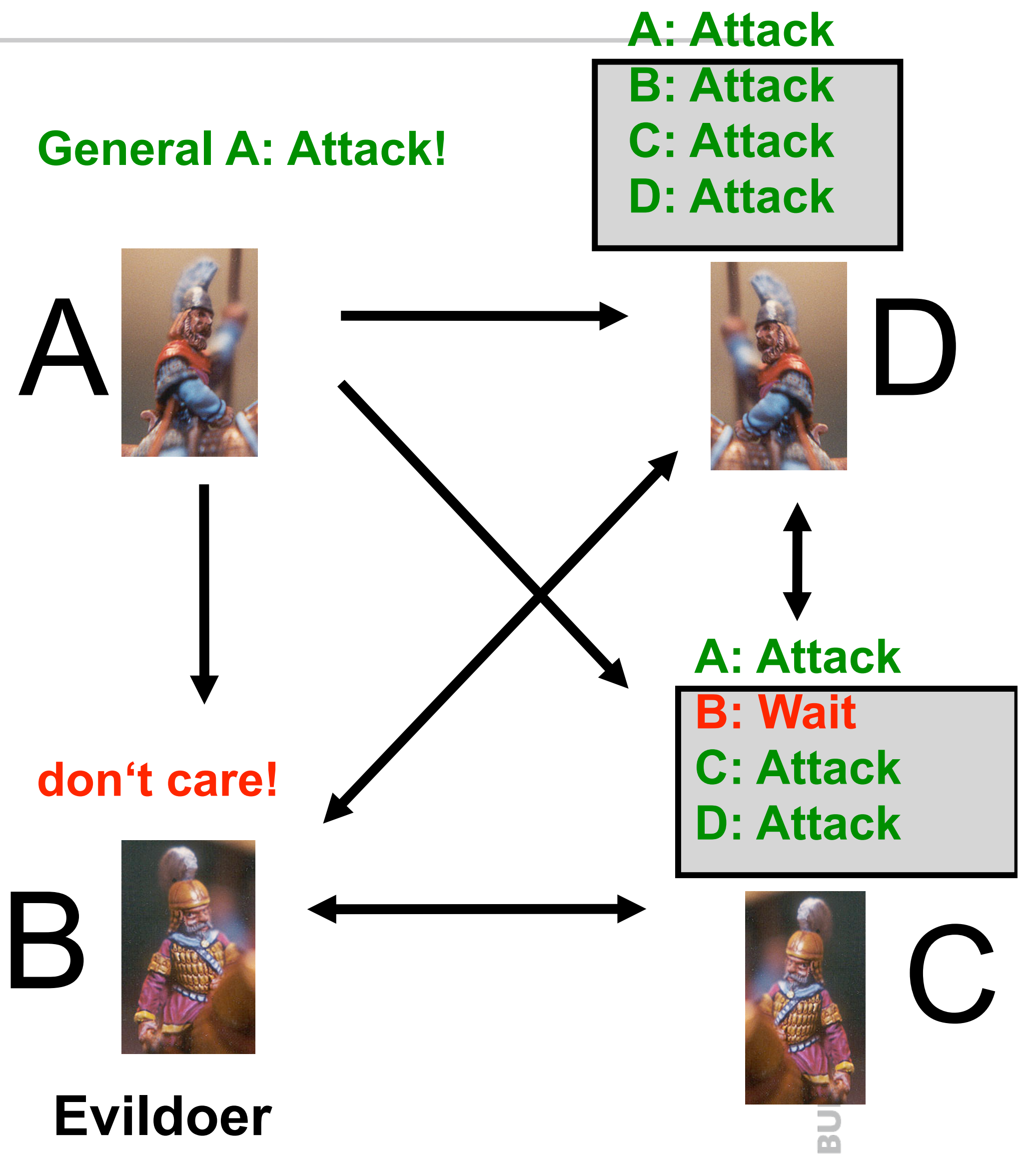
Byzantine Agreement

- Theorem
  - The problem of three byzantine generals cannot be solved (without cryptography)
  - It can be solved for 4 generals
- Consider: 1 general, 3 officers problem
  - If the general is loyal then all loyal officers will obey the command
  - In any case distribute the received commans to all fellow officers
  - What if the general is the renegade?



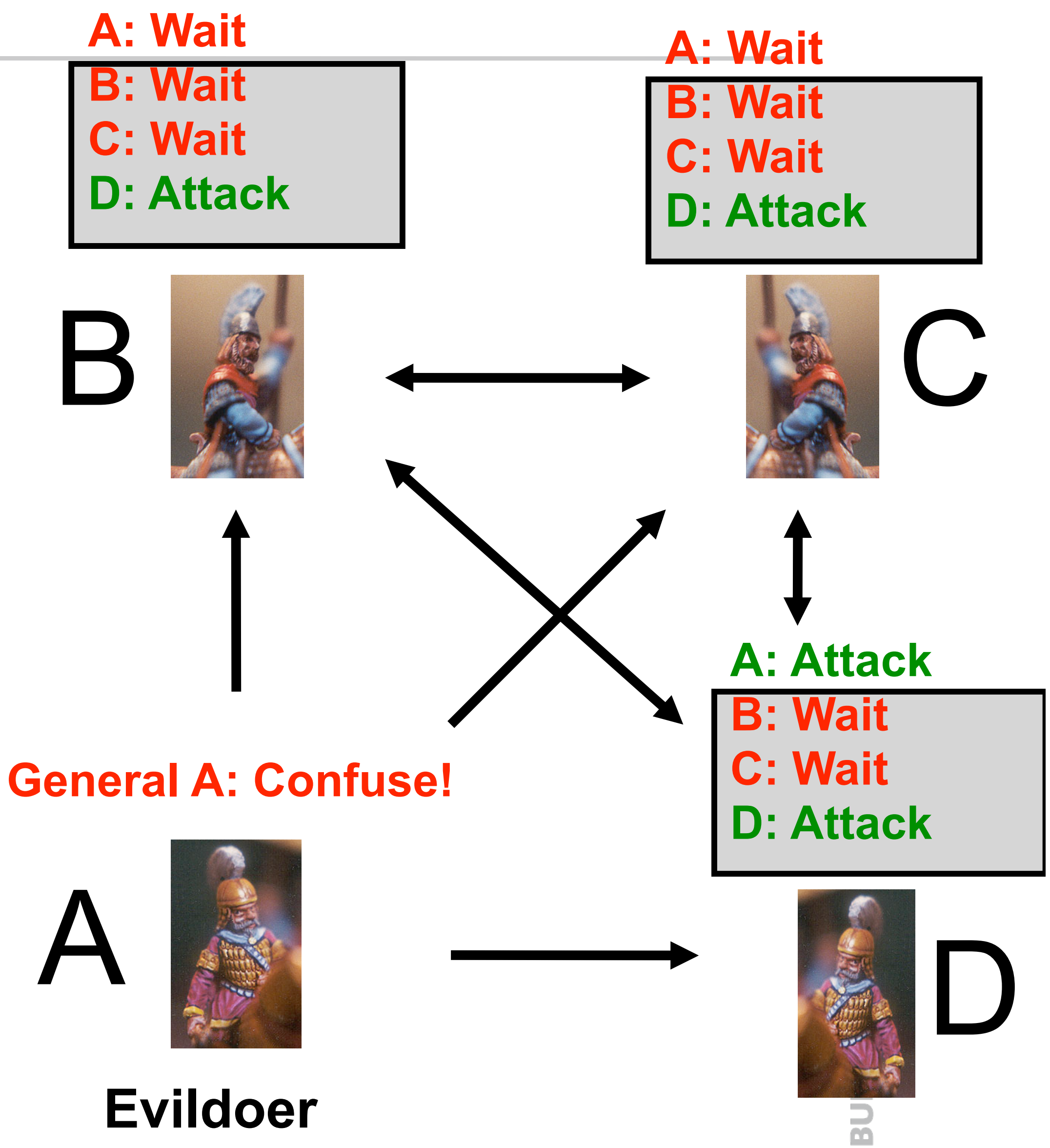
Byzantine Agreement

- Theorem
  - The problem of four byzantine generals can be solved (without cryptography)
- Algorithm
  - General A sends his command to all other generals
    - A sticks to his command if he is honest
  - All other generals forward the received command to all other generals
  - Every generals computes the majority decision of the received commands and follows this command



Byzantine Agreement

- Theorem
  - The problem of four byzantine generals can be solved (without cryptography)
- Algorithm
  - General A sends his command to all other generals
    - A sticks to his command if he is honest
  - All other generals forward the received command to all other generals
  - Every generals computes the majority decision of the received commands and follows this command



General Solution of Byzantine Agreement

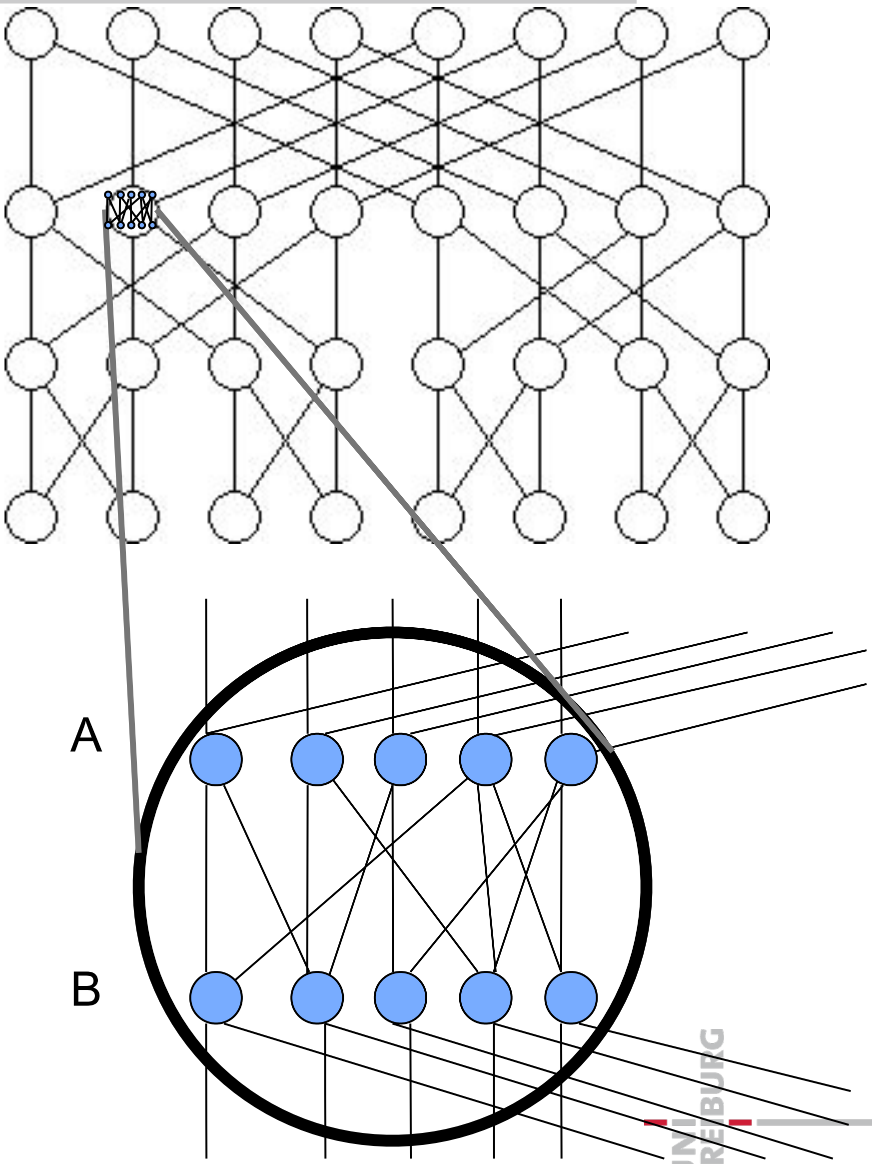
- Theorem
  - If m generals are traitors then 2m+1 generals must be honest to get a Byzantine Agreement
- This bound is sharp if one does not rely on cryptography
- Theorem
  - If a digital signature scheme is working, then an arbitrarily large number of betraying generals can be dealt with
- Solution
  - Every general signs his command
  - All commands are shared together with the signature
  - Inconsistent commands can be detected
  - The evildoer can be exposed

P2P and Byzantine Agreement

- Digital signature can solve the problem of malign peers
- Problem: Number of messages
  - $O(n^2)$ messages in the whole network (for n peers)
- In „Scalable Byzantine Agreement“ von Clifford Scott Lewis und Jared Saia, 2003
  - a scalable algorithm was presented
  - can deal with n/6 evil peers
    - if they do not influence the network structure
  - use only O(log n) messages per node in the expectation
  - find agreement with high probability

Network of Lewis and Saia

- Butterfly network with clusters of size c log n
  - clusters are bipartite expander graphs
  - Bipartite graph
    - is a graph with disjoint node sets A and B where no edges connect the nodes within A or within B
  - Expander graph
    - A bipartite graph is an expander graph if for each subset X of A the number of neighbors in B is at least c|X| for a fixed constant c>0
    - and vice versa for the subsets in B



Discussion

- Advantage
  - Very efficient, robust and simple method
- Disadvantage
  - Strong assumptions
    - The attacker does not know the internal network structure
- If the attacker knows the structure
  - Eclipse attack!

Cuckoo Hashing for Security

- Awerbuch, Scheideler, Towards Scalable and Robust Overlay Networks
- Problem:
  - Rejoin attacks
- Solution:
  - Chord network combined with
  - Cuckoo Hashing
  - Majority condition:
    - honest peers in the neighborhood are in the majority
  - Data is stored with O(log n) copies

Cuckoo Hashing

- C
  -
  -
- Ir
  -
  -

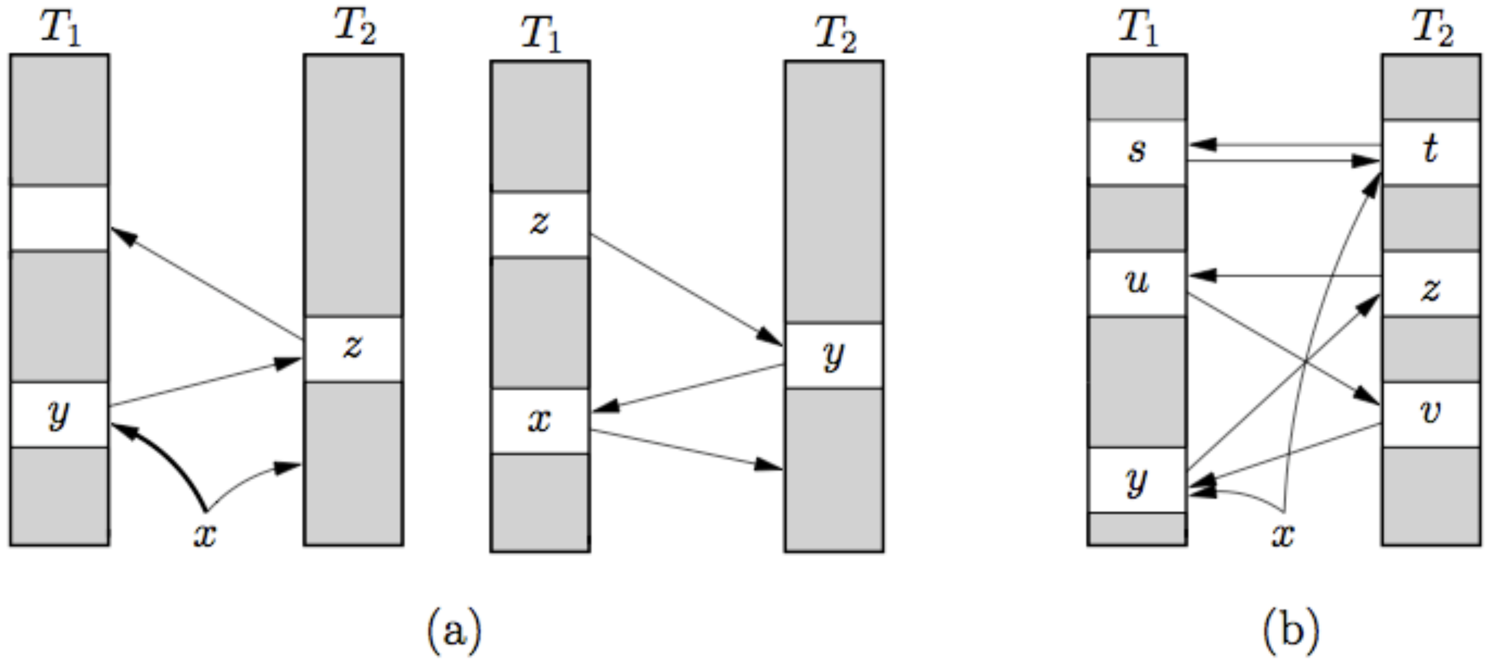


Fig. 1. Examples of CUCKOO HASHING insertion. Arrows show possibilities for moving keys. (a) Key x is successfully inserted by moving keys y and z from one table to the other. (b) Key x cannot be accommodated and a rehash is necessary.

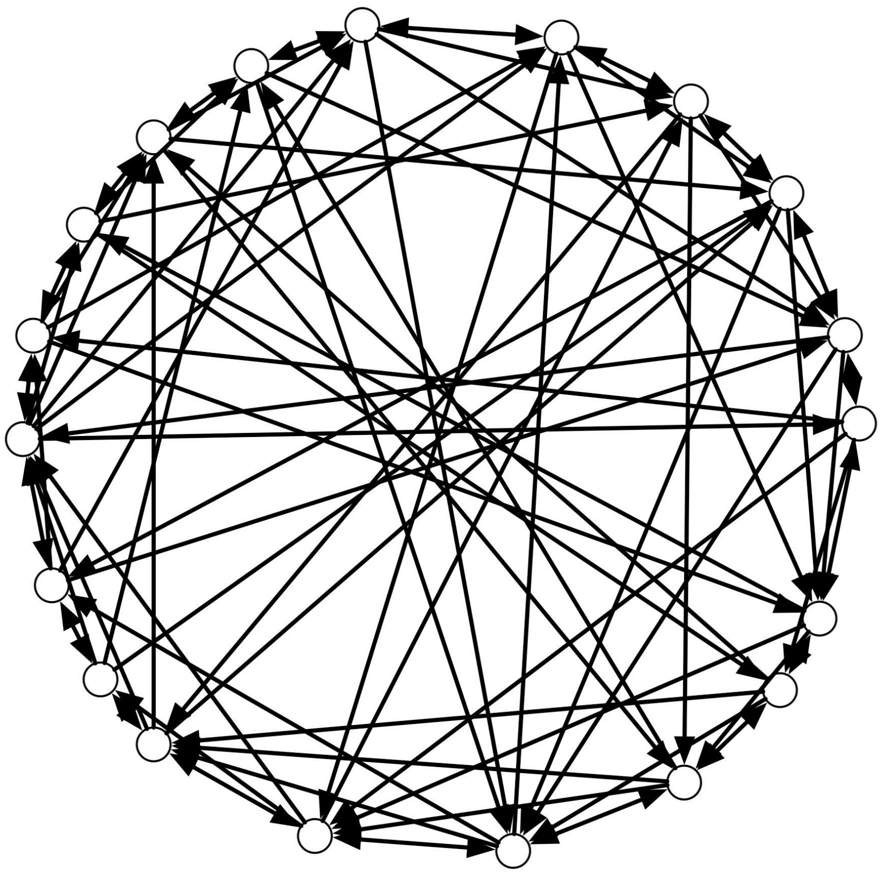
From Cuckoo Hashing
Rasmus Pagh, Flemming Friche Rodler
2004

Efficiency of Cuckoo Hashing

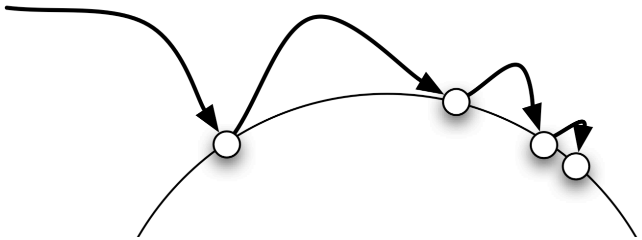
- Theorem
  - Let ϵ>0 then if at most n elements are stored, then Cuckoo Hashing needs a hash space of 2n+ϵ.
- Three hash functions increase the load factor from 1/2 to 91%
- Insert
  - needs O(1) steps in the expectation
  - O(log n) with high probability
- Lookup
  - needs two steps

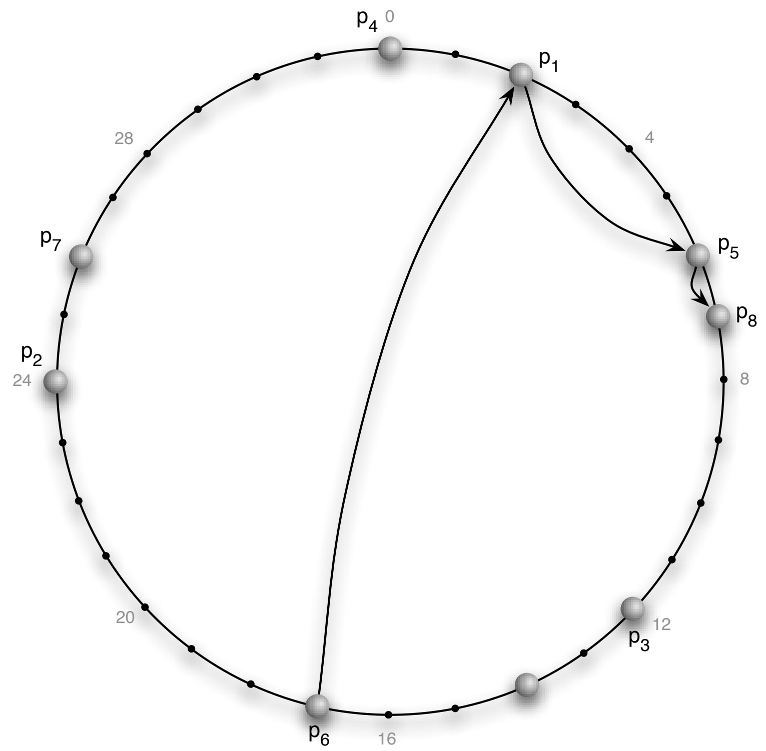
Chord

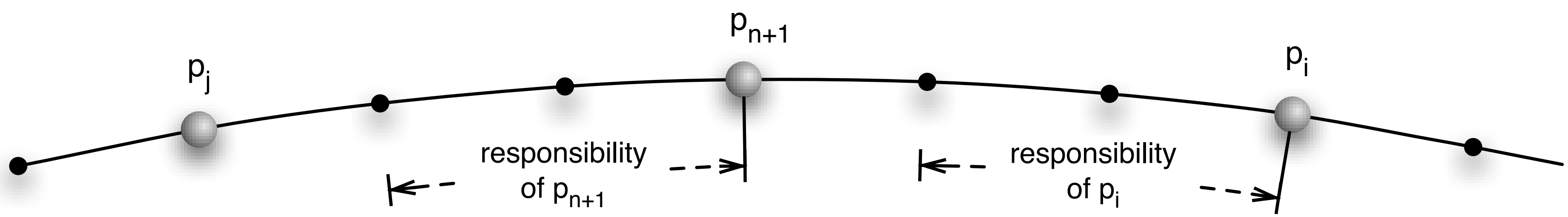
- Ion Stoica, Robert Morris, David Karger, M. Frans Kaashoek and Hari Balakrishnan (2001)
- Distributed Hash Table
  - range {0,..,2^m-1}
  - for sufficient large m
- for this work the range is seen as [0,1)
- Network
  - ring-wise connections
  - shortcuts with exponential increasing distance



Lookup in Chord

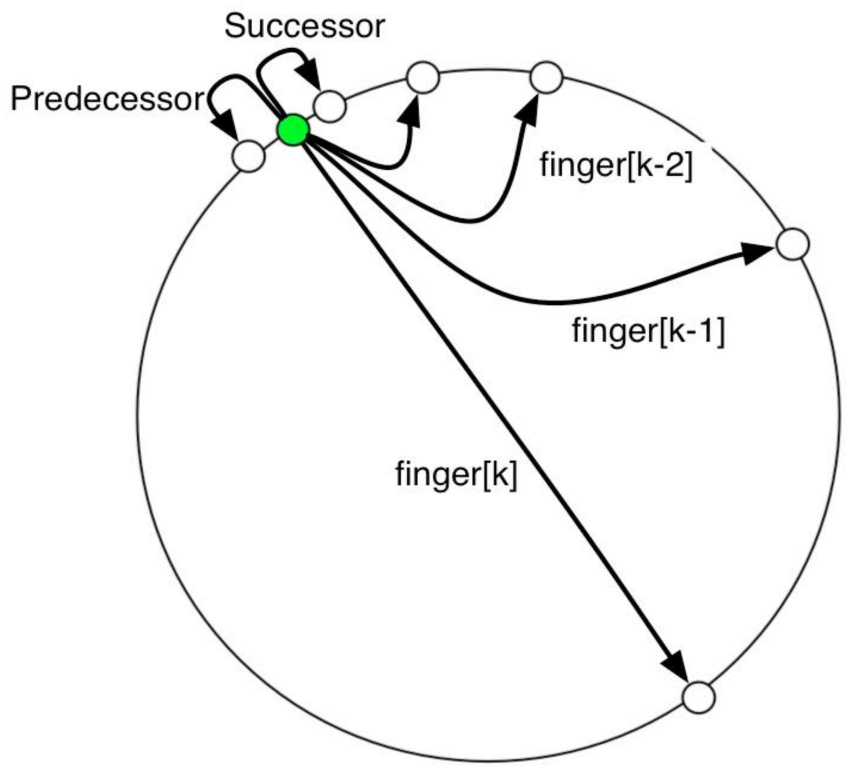






Data Structure of Chord

- For each peer
  - successor link on the ring
  - predecessor link on the ring
  - for all $i \in \{0,..,m-1\}$
    - Finger[i] := the peer following the value $r_V(b+2^i)$s
- For small i the finger entries are the same
  - store only different entries
- Chord
  - needs $O(\log n)$ hops for lookup
  - needs $O(\log^2 n)$ messages for inserting and erasing of peers



Cuckoo Hashing for Security

- Given n honest peers and ϵ n dishonest peers
- Goal
  - For any adversarial attack the following properties for every interval $I \subseteq [0, 1)$ of size at least $(c \log n)/n$ we have
  - Balancing condition
    - I contains $\Theta(|I| \cdot n)$ nodes
  - Majority condition
    - the honest nodes in I are in the majority
- Then all majority decisions of $O(\log n)$ nodes give a correct result

Rejoin Attacks

- Secure hash functions for positions in the Chord
  - if one position is used
  - then in an O(log n) neighborhood more than half is honest
  - if more than half of al peers are honest
- Rejoin attacks
  - use a small number of attackers
  - check out new addresses until attackers fall in one interval
  - then this neighborhood can be ruled by the attackers

The Cuckoo Rule for Chord

- Notation
  - a region is an interval of size $1/2^r$ in [0, 1) for some integer r that starts at an integer multiple of $1/2^r$
  - There are exactly 2^r regions
  - A k-region is a region of size (closest from above to) k/n, and for any point $x \in [0, 1)$
  - the k-region $R_k(x)$ is the unique k-region containing x.
- Cuckoo rule
  - If a new node v wants to join the system, pick a random $x \in [0, 1)$.
  - Place v into x and move all nodes in $R_k(x)$ to points in [0, 1) chosen uniformly at random
    - (without replacing any further nodes).
- Theorem
  - For any constants ϵ and k with $\epsilon < 1-1/k$, the cuckoo rule with parameter k satisfies the balancing and majority conditions for a polynomial number of rounds, with high probability, for any adversarial strategy within our model.
  - The inequality $\epsilon < 1 - 1/k$ is sharp

Operations

- Data storage
  - each data item is stored in the $O(\log^3 n)$ neighborhood as copies
- Primitives
  - robust hash functions
    - safe against attacks
  - majority decisions of each operation
  - use multiple routes for targeting location

Efficiency

- Lookup
  - works correctly with high probability
  - can be performed with $O(\log^5 n)$ messages
- Inserting of data
  - works in polylogarithmic time
  - needs $O(\log^5 n)$ messages
- Copies stored of each data: $O(\log^3 n)$

Discussion

- Advantage
  - Cuckoo Chord is safe against adversarial attacks
  - Cuckoo rule is simple and effective
- Disadvantage
  - Computation of secure hash function is complex
  - Considerate overhead for communication
- Theoretical breakthrough
- Little impact to the practical world

Peer-to-Peer Networks
13 Security

Christian Schindelhauer
Technical Faculty
Computer-Networks and Telematics
University of Freiburg