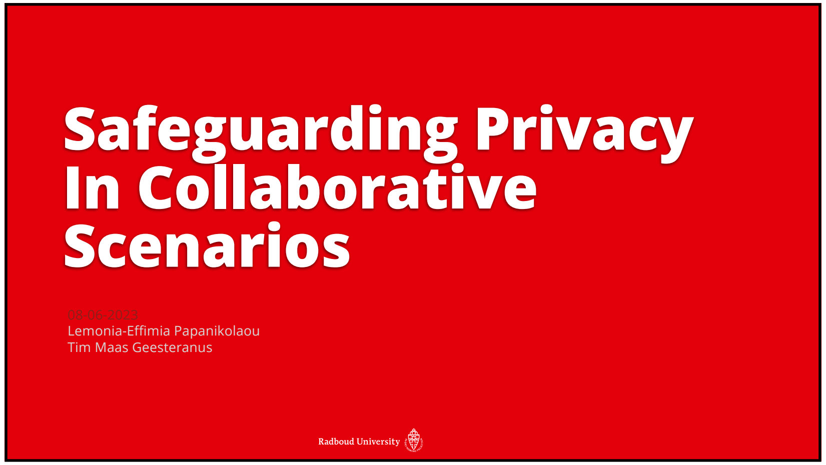

Safeguarding Privacy In Collaborative Scenarios

08-06-2023

Lemonia-Effimia Papanikolaou
Tim Maas Geesteranus

Radboud University

1

PICTURE THIS SCENARIO

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2

YES!

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3

YES!

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4

BUT

Radboud University

5

OR WHAT IF...

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6

OR WHAT IF...

Radboud University

7

OR WHAT IF...

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8

OR WHAT IF...

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9

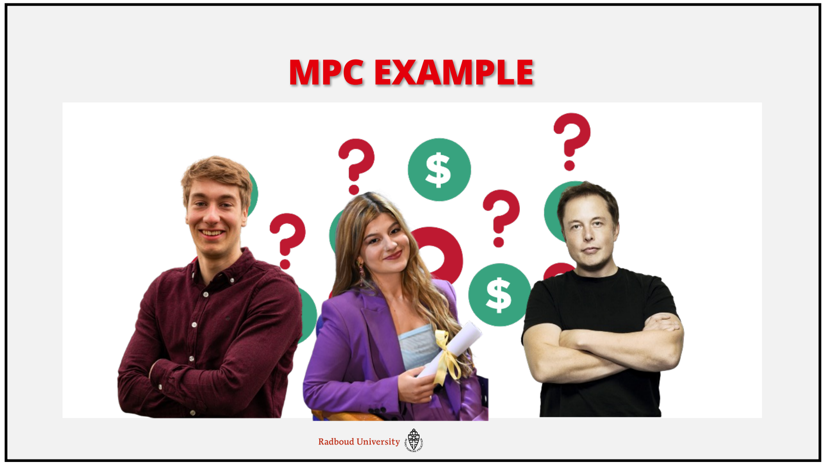
Secure Multiparty Computation

08-06-2023

Lemonia-Effimia Papanikolaou
Tim Maas Geesteranus

Radboud University

10



MPC EXAMPLE

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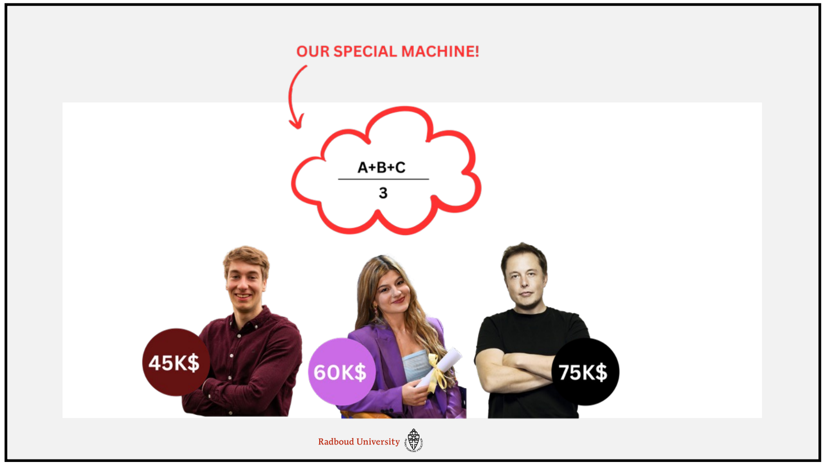

OUR SPECIAL MACHINE!

$$\frac{A+B+C}{3}$$

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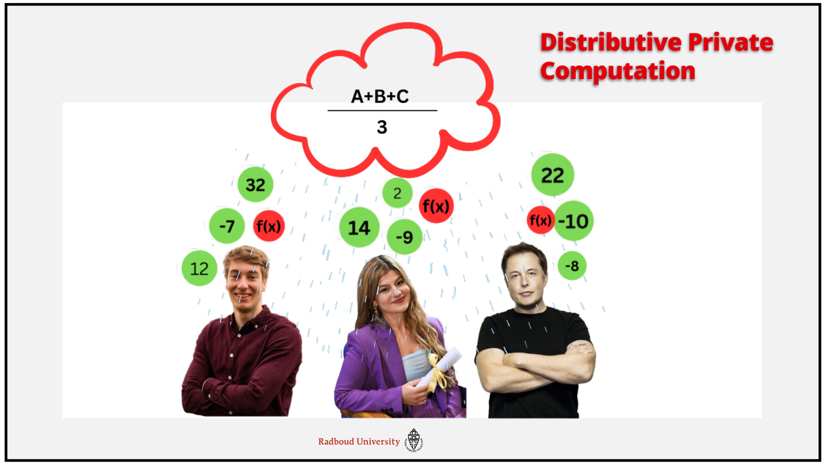
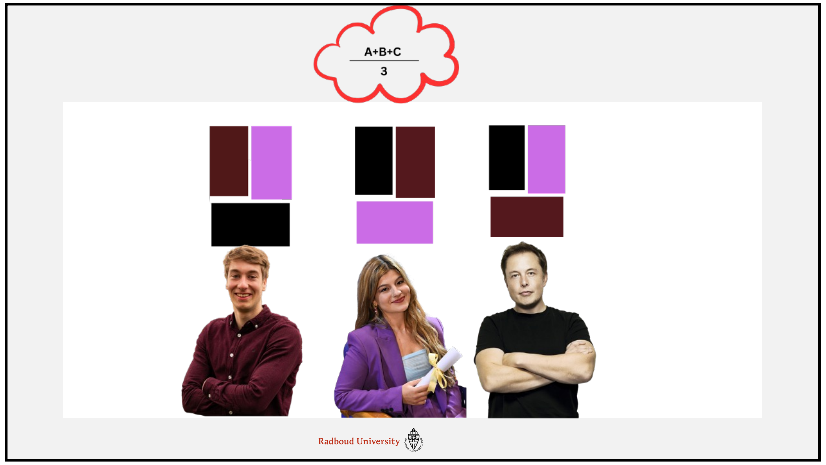
12



Distributive Private Computation

13



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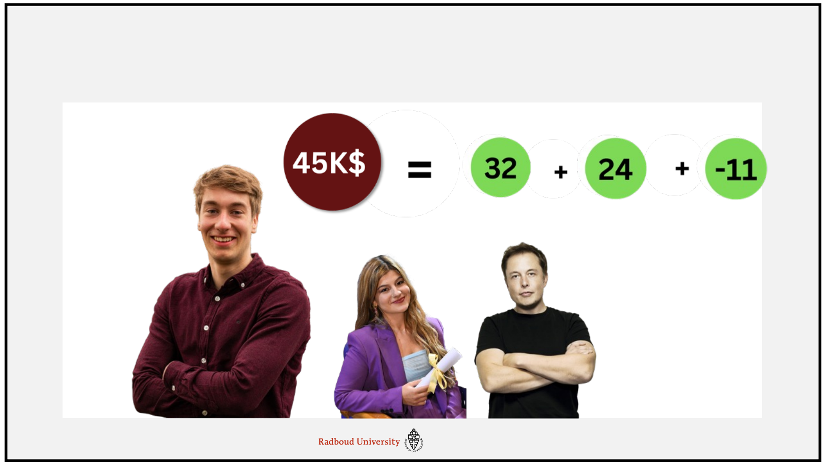

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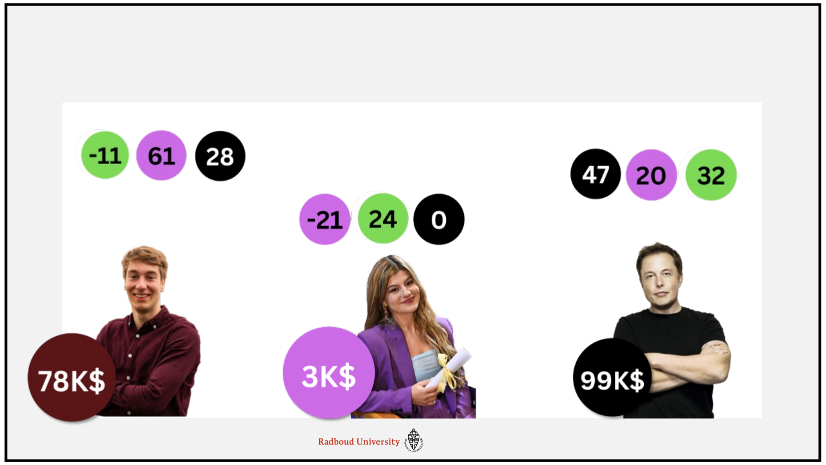

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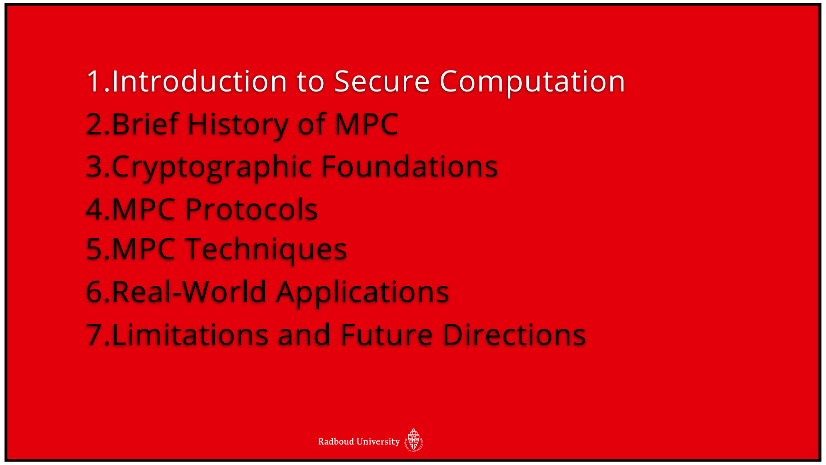

1. Introduction to Secure Computation
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7. Limitations and Future Directions

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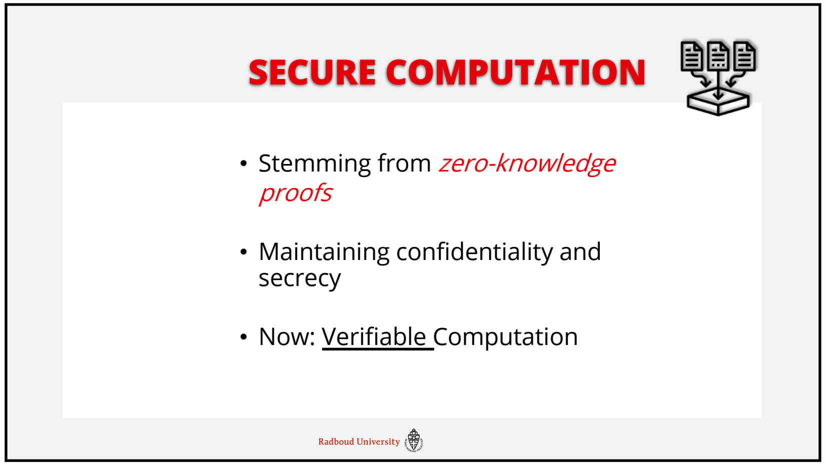
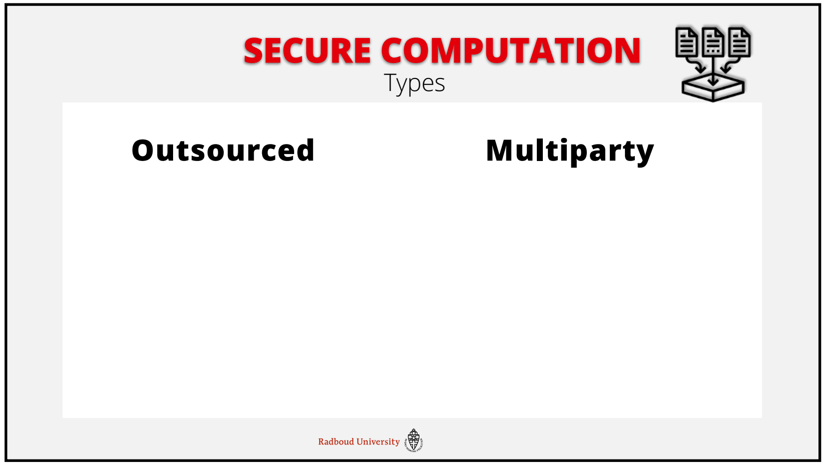


SECURE COMPUTATION

- Stemming from *zero-knowledge proofs*
- Maintaining confidentiality and secrecy
- Now: Verifiable Computation

19

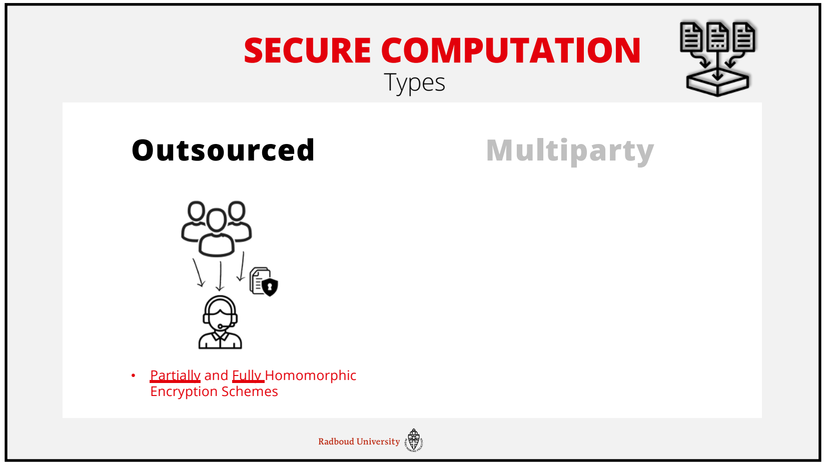


SECURE COMPUTATION

Types

Outsourced **Multiparty**

20



SECURE COMPUTATION
Types

Outsourced

Multiparty

- Partially and Fully Homomorphic Encryption Schemes

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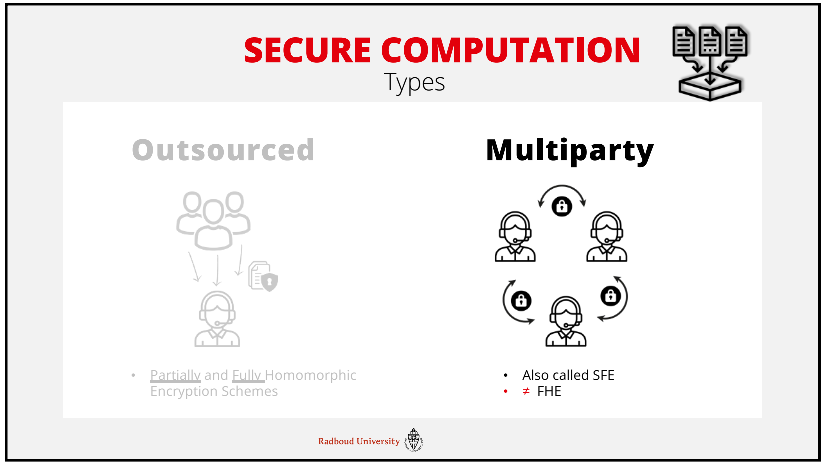

SECURE COMPUTATION
Types

Outsourced

Multiparty

- Partially and Fully Homomorphic Encryption Schemes

- Also called SFE
- ≠ FHE

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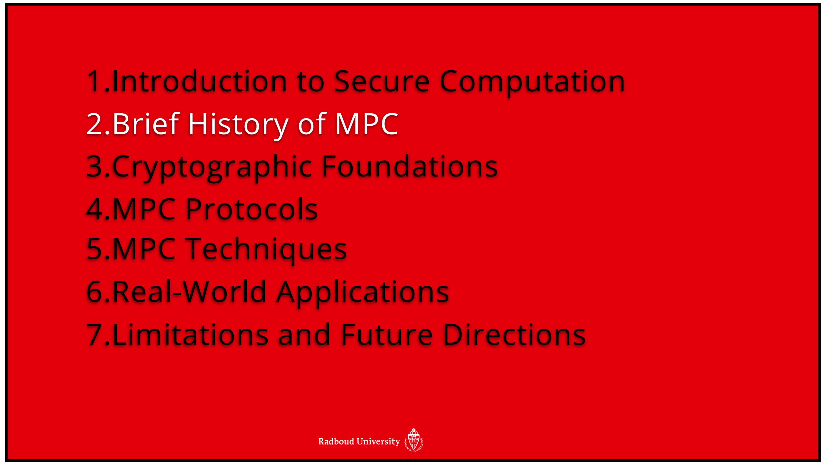

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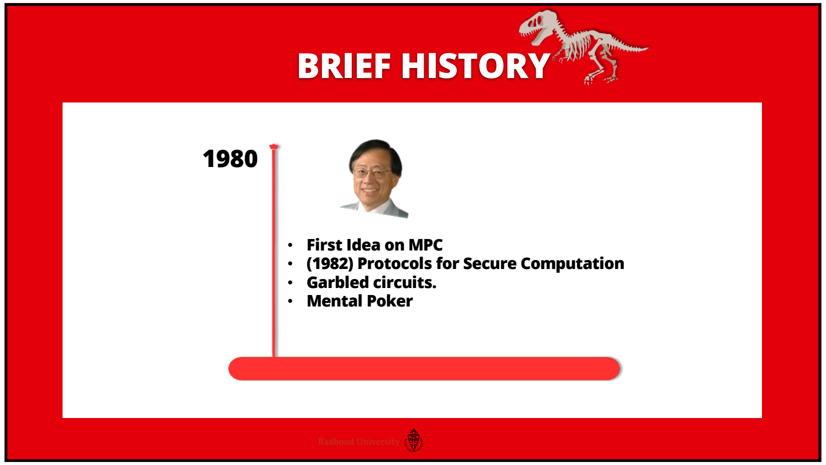

BRIEF HISTORY

1980

- **First Idea on MPC**
- **(1982) Protocols for Secure Computation**
- **Garbled circuits.**
- **Mental Poker**

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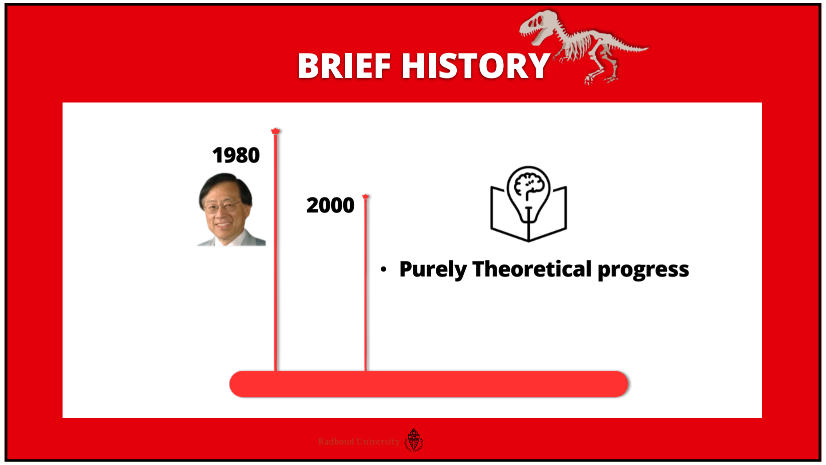

BRIEF HISTORY

- Purely Theoretical progress

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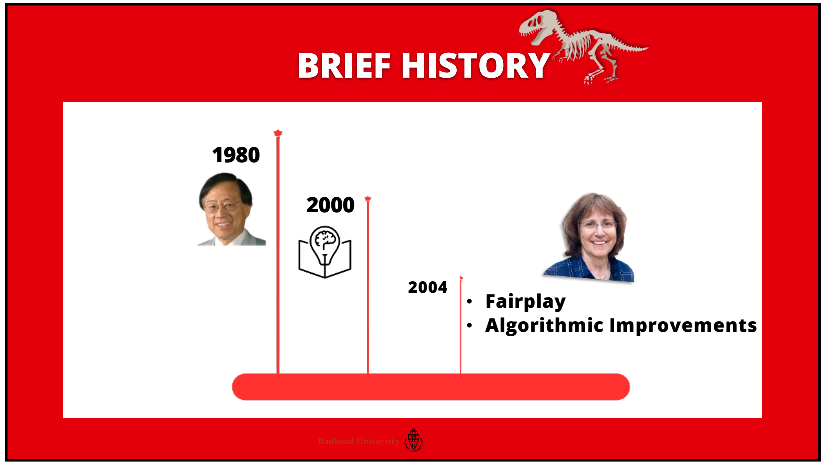

BRIEF HISTORY

- Fairplay
- Algorithmic Improvements

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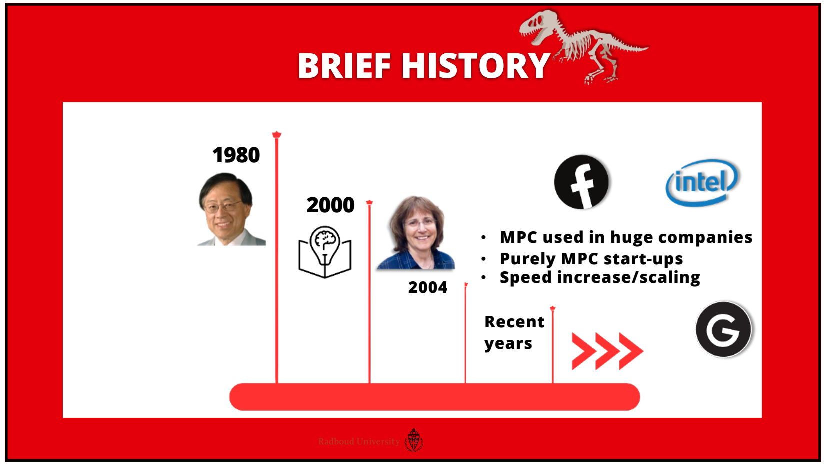

BRIEF HISTORY

- MPC used in huge companies
- Purely MPC start-ups
- Speed increase/scaling

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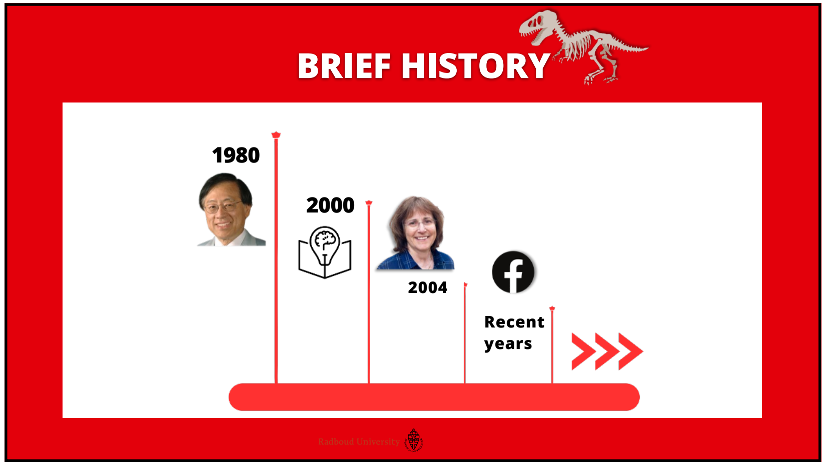

BRIEF HISTORY

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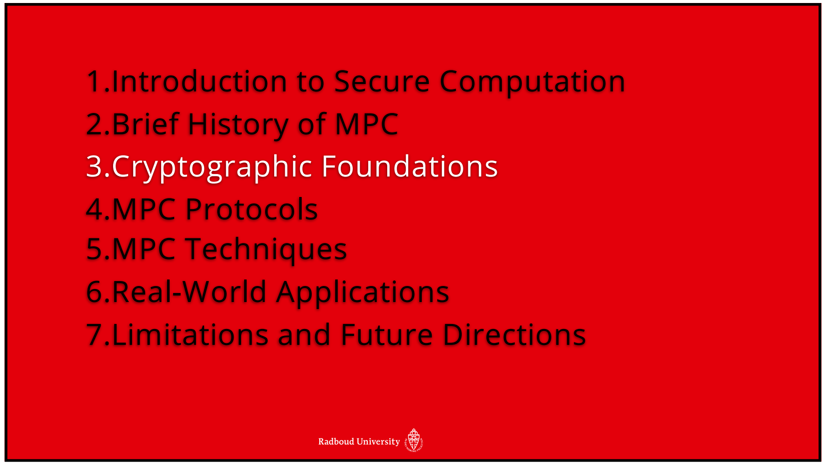

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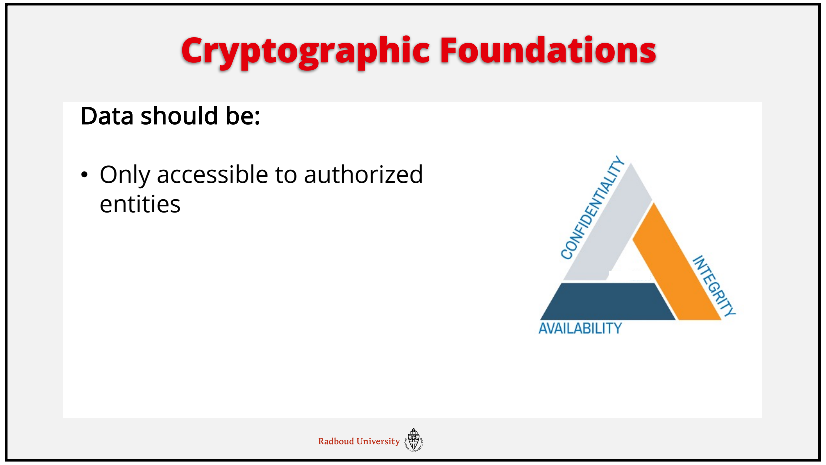

Cryptographic Foundations

Data should be:

- Only accessible to authorized entities

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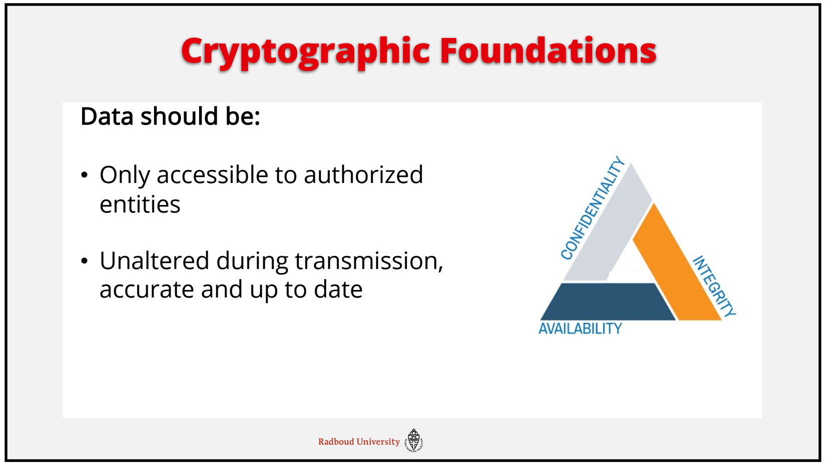

Cryptographic Foundations

Data should be:

- Only accessible to authorized entities
- Unaltered during transmission, accurate and up to date

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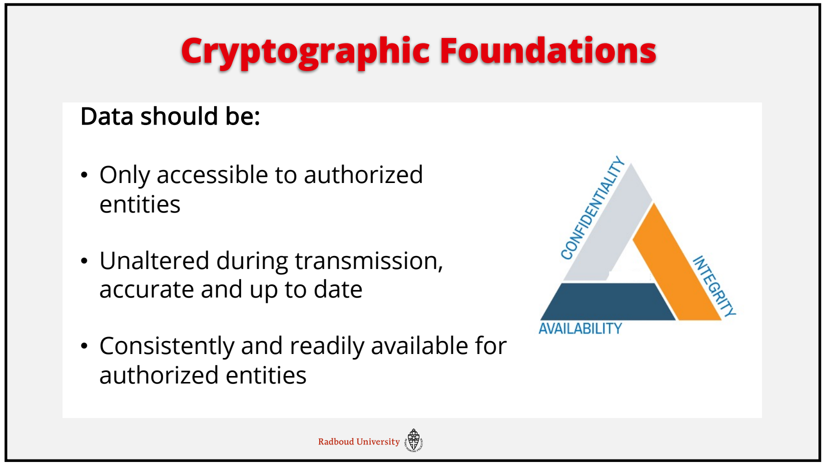

Cryptographic Foundations

Data should be:

- Only accessible to authorized entities
- Unaltered during transmission, accurate and up to date
- Consistently and readily available for authorized entities

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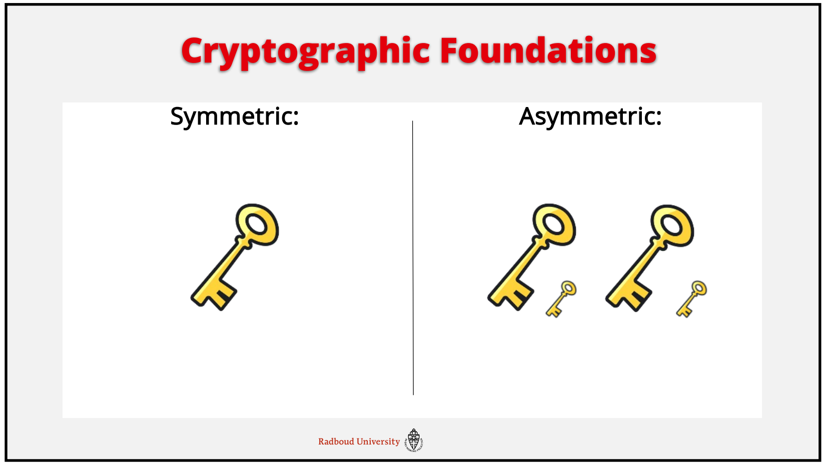

Cryptographic Foundations

Symmetric:

Asymmetric:

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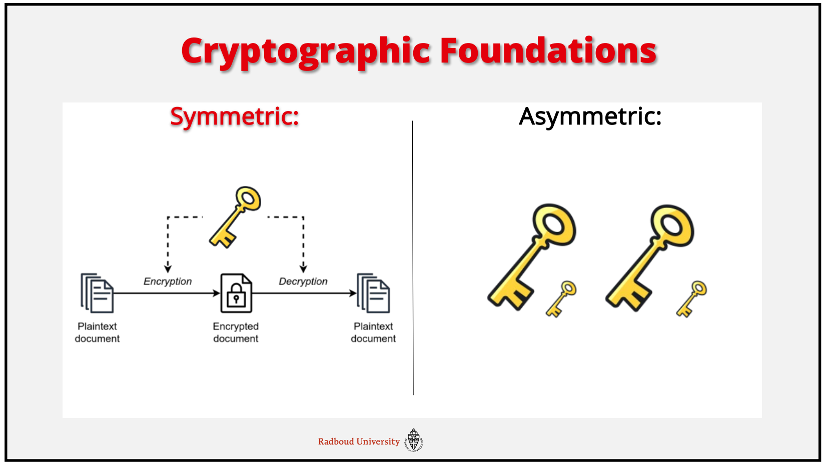

Cryptographic Foundations

Symmetric:

Encryption

Decryption

Plaintext document

Encrypted document

Plaintext document

Asymmetric:

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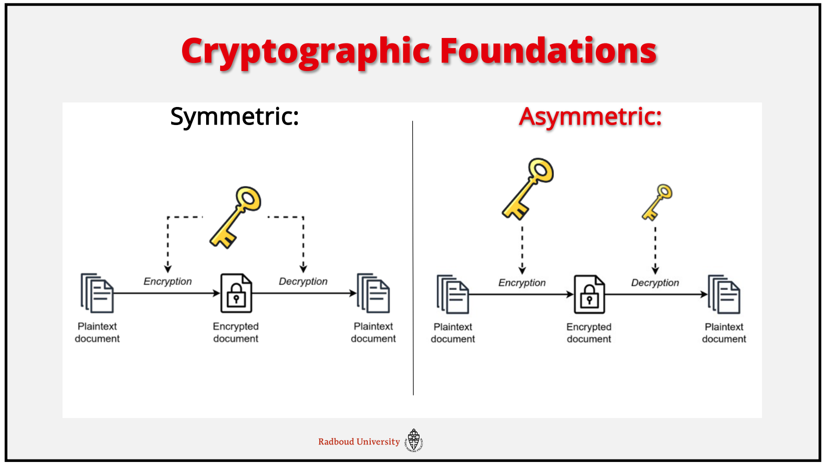

Cryptographic Foundations

Symmetric:

Encryption

Decryption

Plaintext document

Encrypted document

Plaintext document

Asymmetric:

Encryption

Decryption

Plaintext document

Encrypted document

Plaintext document

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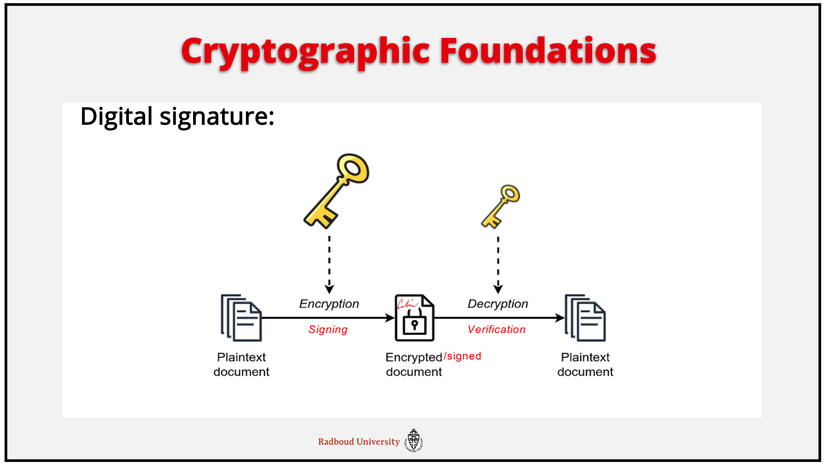

Cryptographic Foundations

Digital signature:

Encryption

Signing

Decryption

Verification

Plaintext document

Encrypted/signed document

Plaintext document

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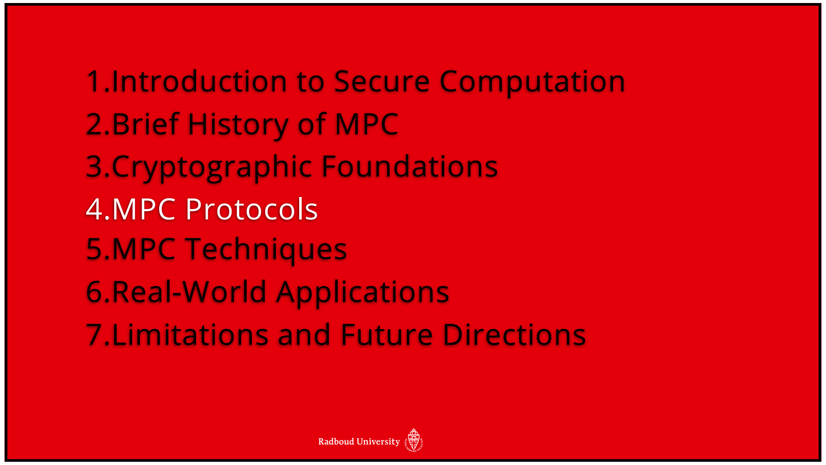

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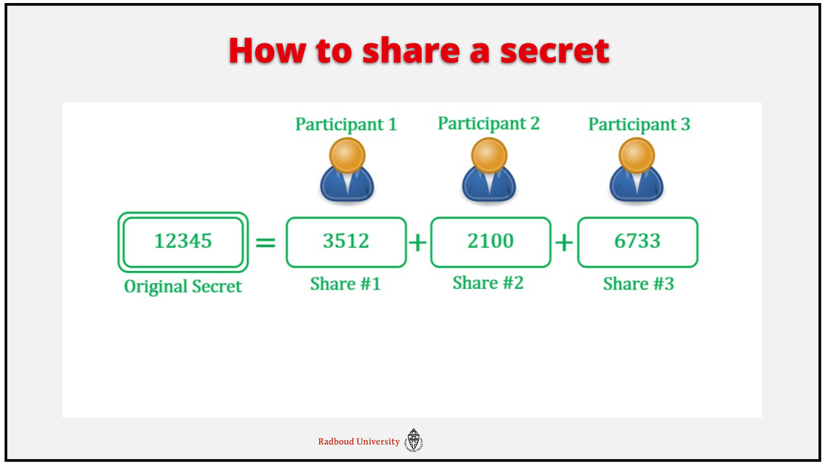

How to share a secret

Participant 1 Participant 2 Participant 3

12345 = 3512 + 2100 + 6733

Original Secret Share #1 Share #2 Share #3

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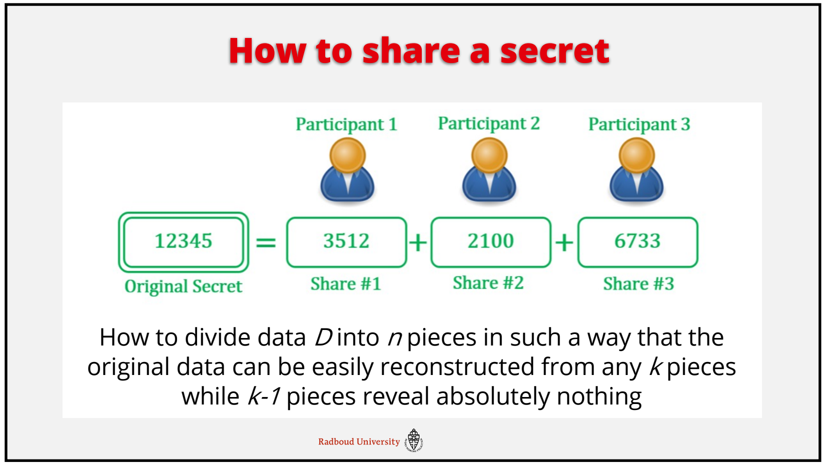

How to share a secret

Participant 1 Participant 2 Participant 3

12345 = 3512 + 2100 + 6733

Original Secret Share #1 Share #2 Share #3

How to divide data *D* into *n* pieces in such a way that the original data can be easily reconstructed from any *k* pieces while *k-1* pieces reveal absolutely nothing

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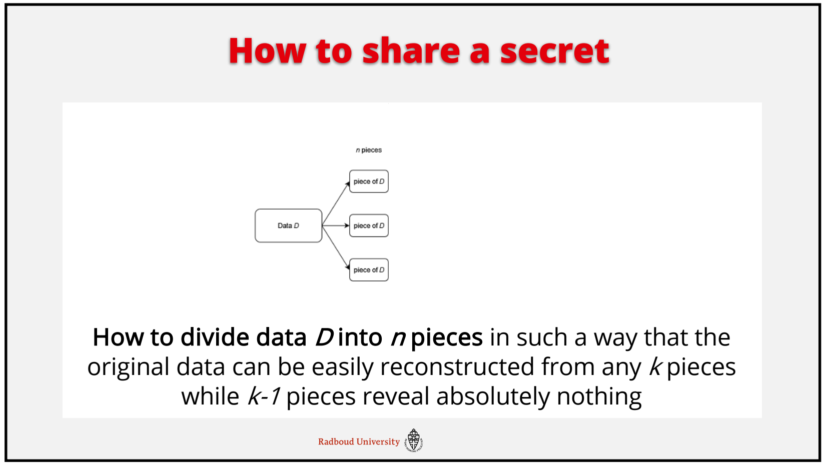


How to share a secret

n pieces

Data *D*

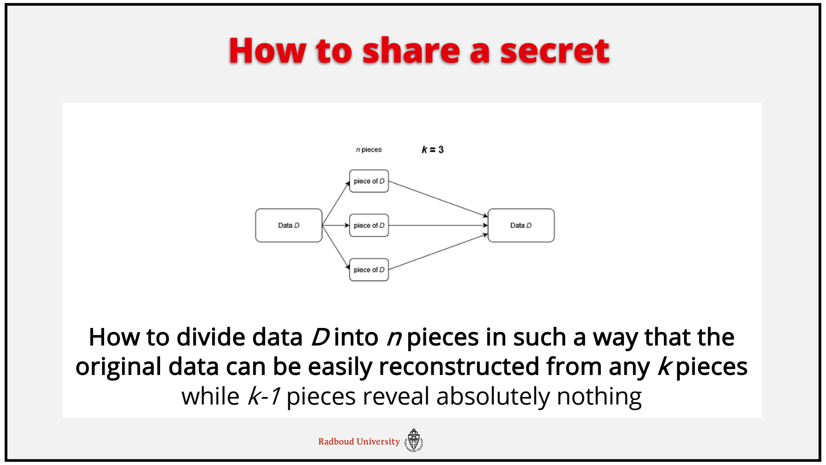
piece of *D*

piece of *D*

piece of *D*

How to divide data *D* into *n* pieces in such a way that the original data can be easily reconstructed from any *k* pieces while *k-1* pieces reveal absolutely nothing

40



How to share a secret

How to divide data *D* into *n* pieces in such a way that the original data can be easily reconstructed from any *k* pieces while *k-1* pieces reveal absolutely nothing

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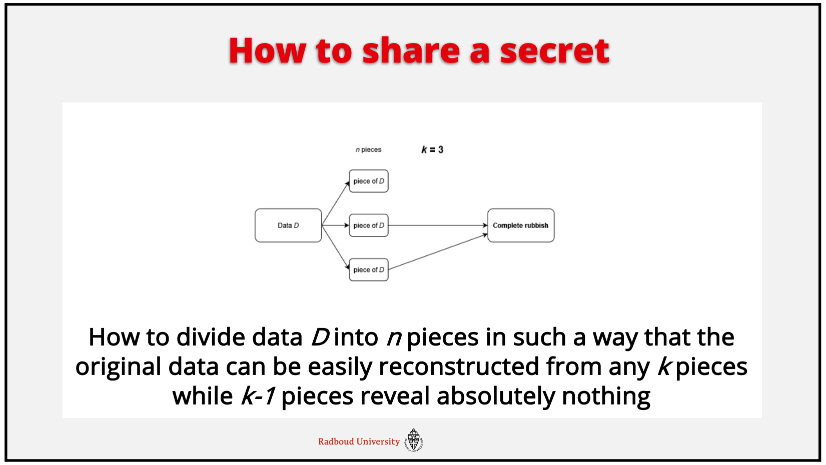

How to share a secret

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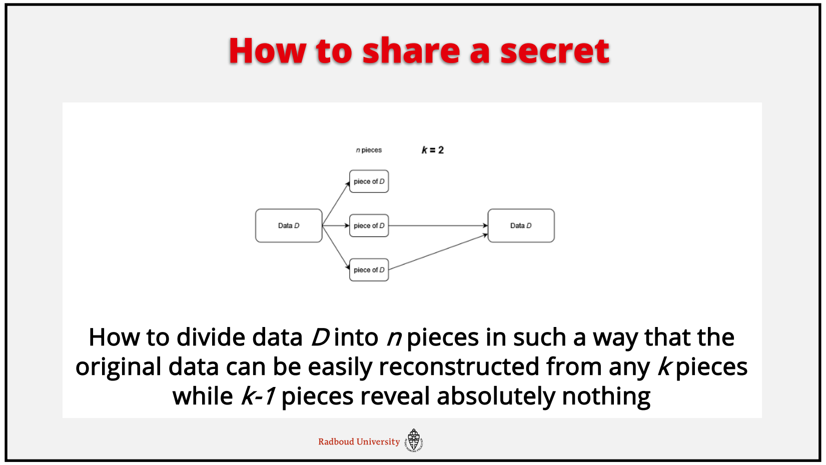

How to share a secret

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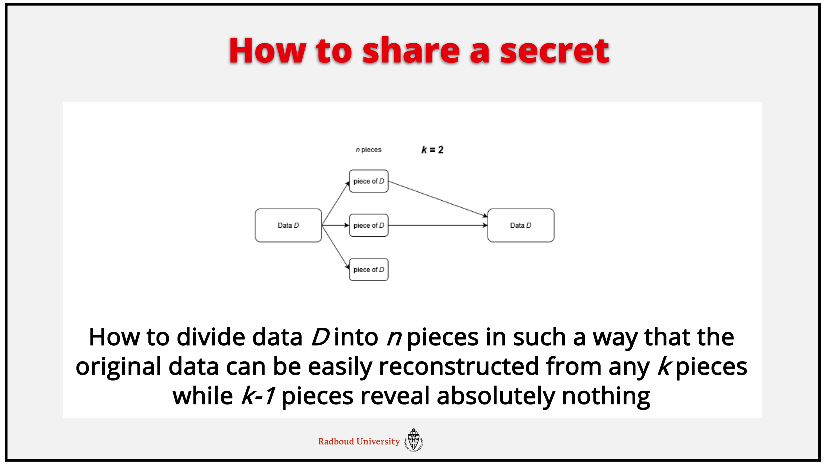

How to share a secret

How to divide data *D* into *n* pieces in such a way that the original data can be easily reconstructed from any *k* pieces while *k-1* pieces reveal absolutely nothing

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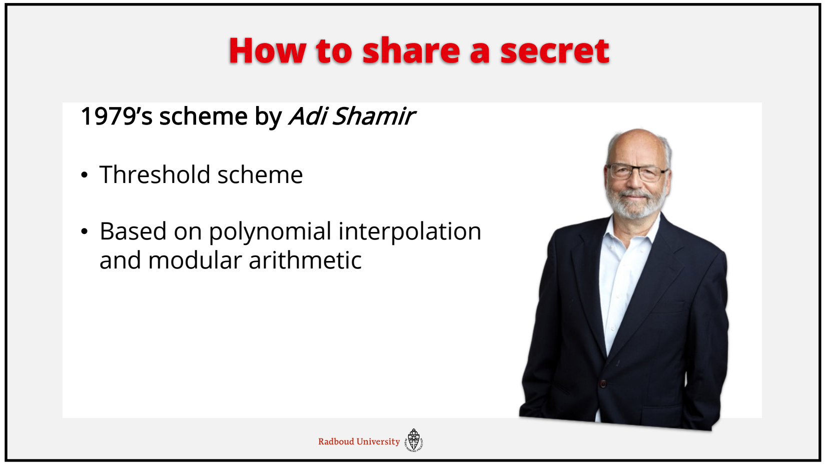

How to share a secret

1979’s scheme by *Adi Shamir*

- Threshold scheme
- Based on polynomial interpolation and modular arithmetic

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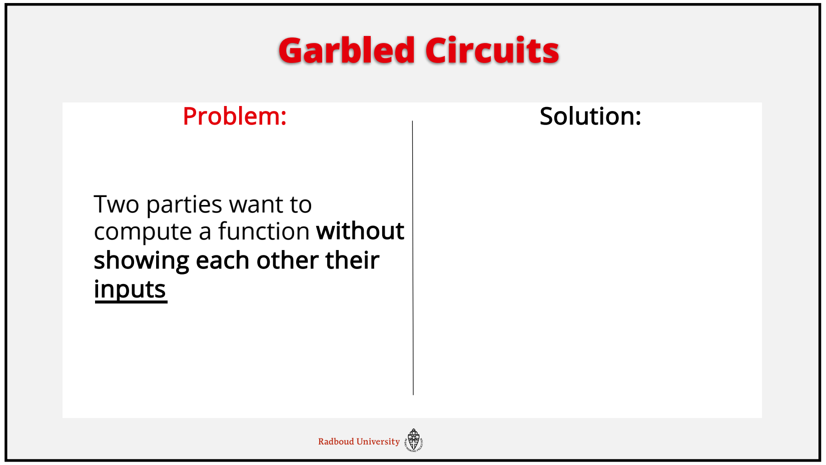

Garbled Circuits

Problem:

Two parties want to compute a function **without showing each other their inputs**

Solution:

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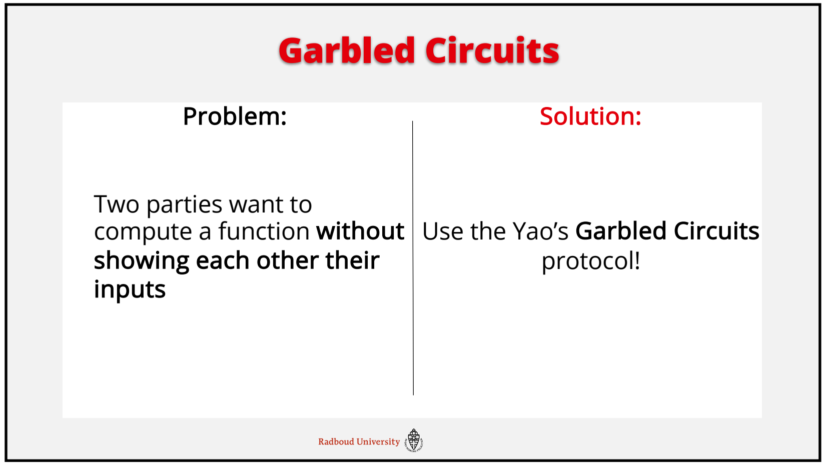

Garbled Circuits

Problem:

Two parties want to compute a function **without showing each other their inputs**

Solution:

Use the Yao’s **Garbled Circuits** protocol!

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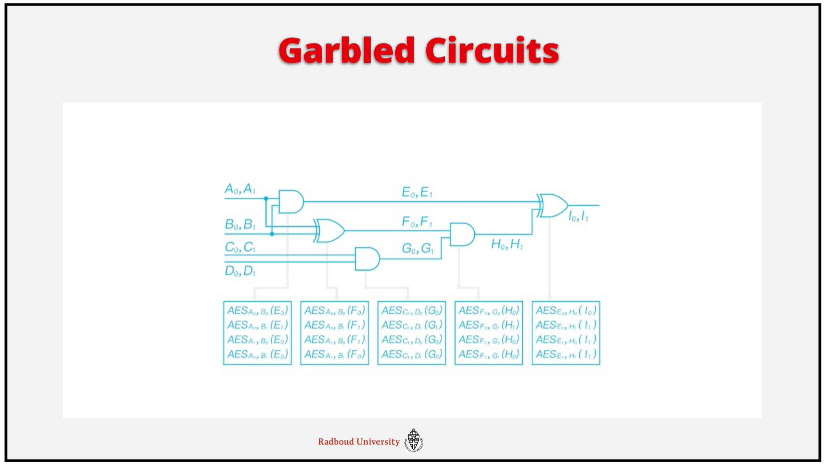

Garbled Circuits

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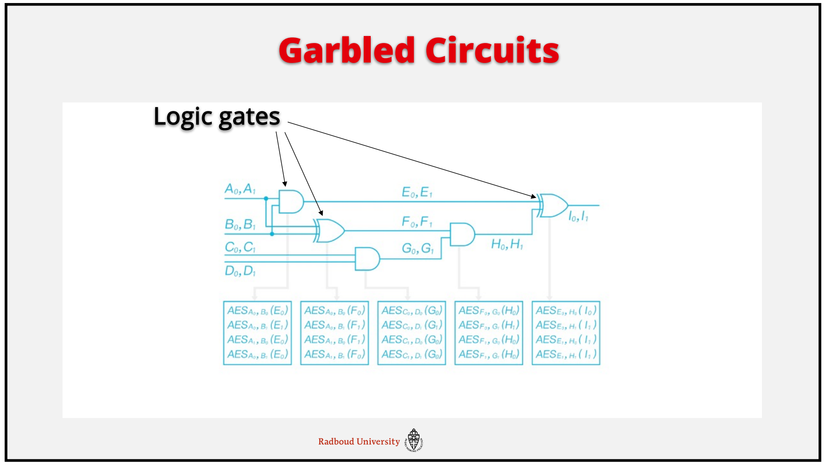
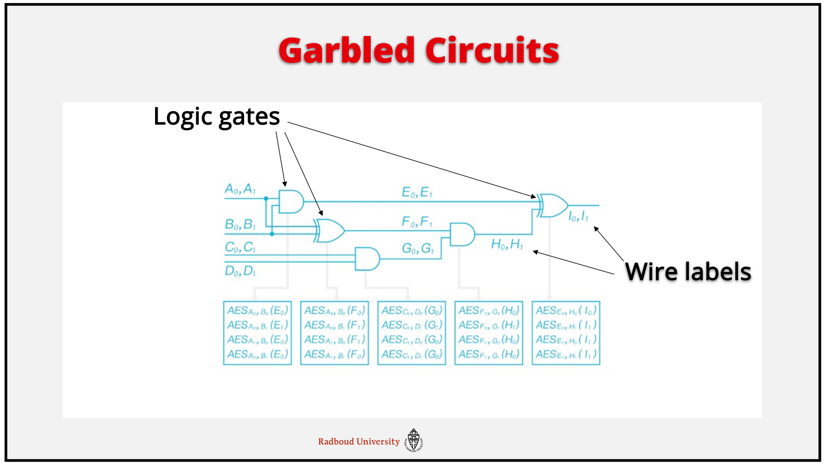


Garbled Circuits

Logic gates

$AES_{A_0, B_0}(E_0)$	$AES_{A_0, B_0}(F_0)$	$AES_{C_0, D_0}(G_0)$	$AES_{F_0, G_0}(H_0)$	$AES_{E_0, H_0}(I_0)$
$AES_{A_0, B_1}(E_1)$	$AES_{A_0, B_1}(F_1)$	$AES_{C_0, D_1}(G_1)$	$AES_{F_0, G_1}(H_1)$	$AES_{E_0, H_1}(I_1)$
$AES_{A_1, B_0}(E_0)$	$AES_{A_1, B_0}(F_1)$	$AES_{C_1, D_0}(G_0)$	$AES_{F_1, G_0}(H_0)$	$AES_{E_1, H_0}(I_1)$
$AES_{A_0, B_1}(E_0)$	$AES_{A_1, B_1}(F_0)$	$AES_{C_1, D_1}(G_0)$	$AES_{F_1, G_1}(H_0)$	$AES_{E_1, H_1}(I_1)$

49



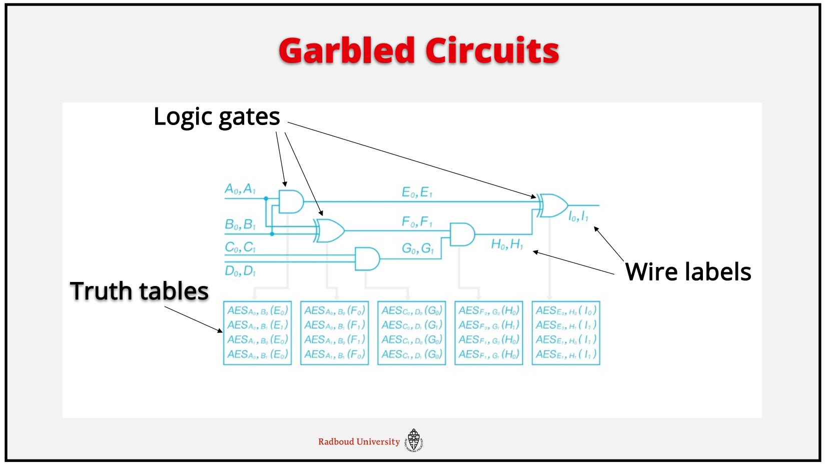
Garbled Circuits

Logic gates

Wire labels

$AES_{A_0, B_0}(E_0)$	$AES_{A_0, B_0}(F_0)$	$AES_{C_0, D_0}(G_0)$	$AES_{F_0, G_0}(H_0)$	$AES_{E_0, H_0}(I_0)$
$AES_{A_0, B_1}(E_1)$	$AES_{A_0, B_1}(F_1)$	$AES_{C_0, D_1}(G_1)$	$AES_{F_0, G_1}(H_1)$	$AES_{E_0, H_1}(I_1)$
$AES_{A_1, B_0}(E_0)$	$AES_{A_1, B_0}(F_1)$	$AES_{C_1, D_0}(G_0)$	$AES_{F_1, G_0}(H_0)$	$AES_{E_1, H_0}(I_1)$
$AES_{A_0, B_1}(E_0)$	$AES_{A_1, B_1}(F_0)$	$AES_{C_1, D_1}(G_0)$	$AES_{F_1, G_1}(H_0)$	$AES_{E_1, H_1}(I_1)$

50



Garbled Circuits

Logic gates

Wire labels

Truth tables

$AES_{A_0, B_0}(E_0)$	$AES_{A_0, B_0}(F_0)$	$AES_{C_0, D_0}(G_0)$	$AES_{F_0, G_0}(H_0)$	$AES_{E_0, H_0}(I_0)$
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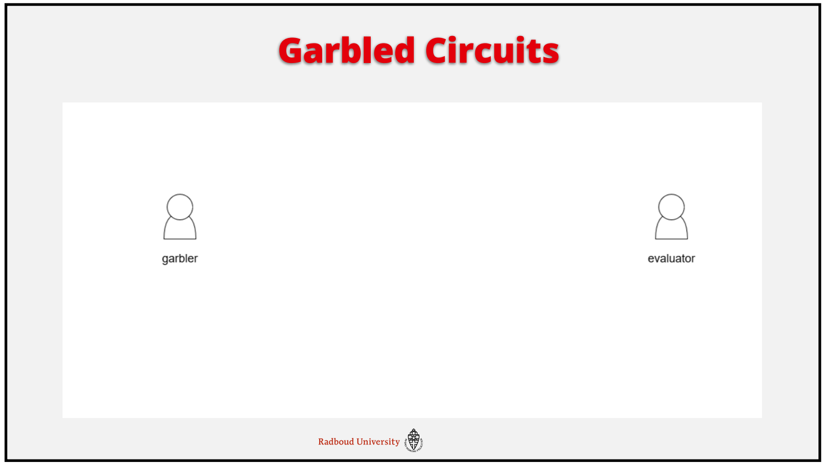
51



Garbled Circuits

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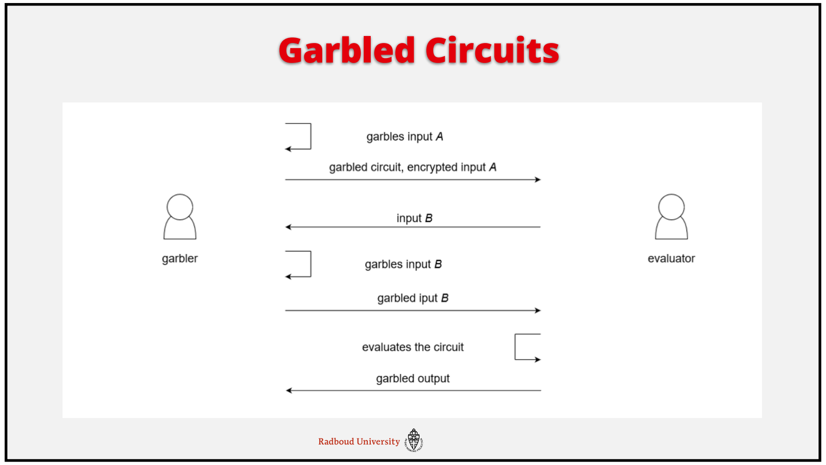

Garbled Circuits

garbler

garbles input *A*

garbled circuit, encrypted input *A*

input *B*

garbles input *B*

garbled input *B*

evaluates the circuit

garbled output

evaluator

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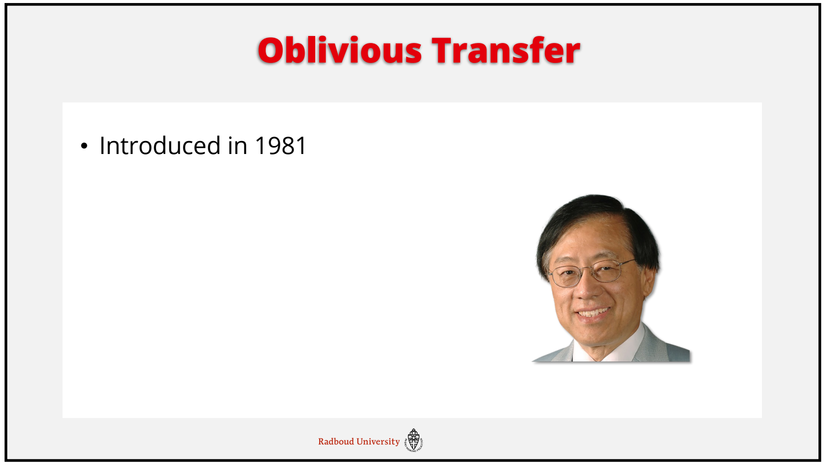

Oblivious Transfer

- Introduced in 1981

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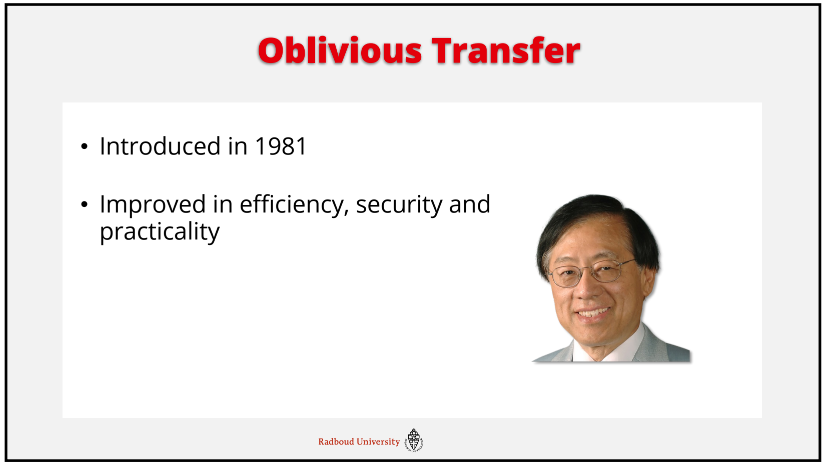

Oblivious Transfer

- Introduced in 1981
- Improved in efficiency, security and practicality

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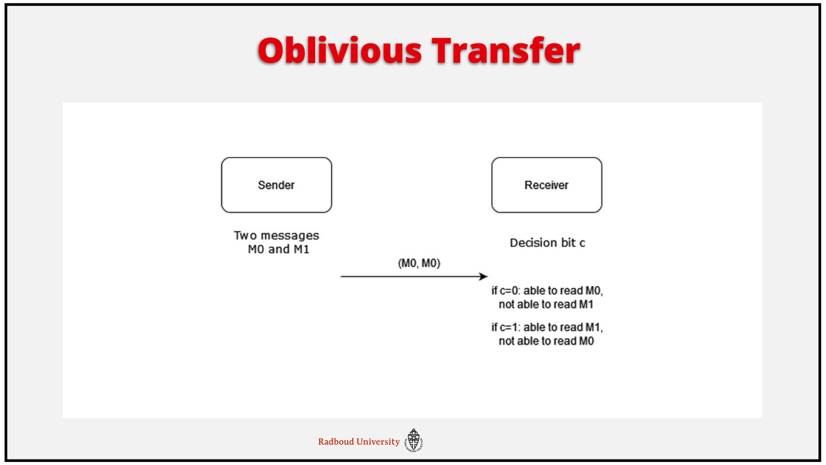

Oblivious Transfer

Sender

Two messages
M0 and M1

(M0, M0)

Receiver

Decision bit c

if c=0: able to read M0,
not able to read M1

if c=1: able to read M1,
not able to read M0

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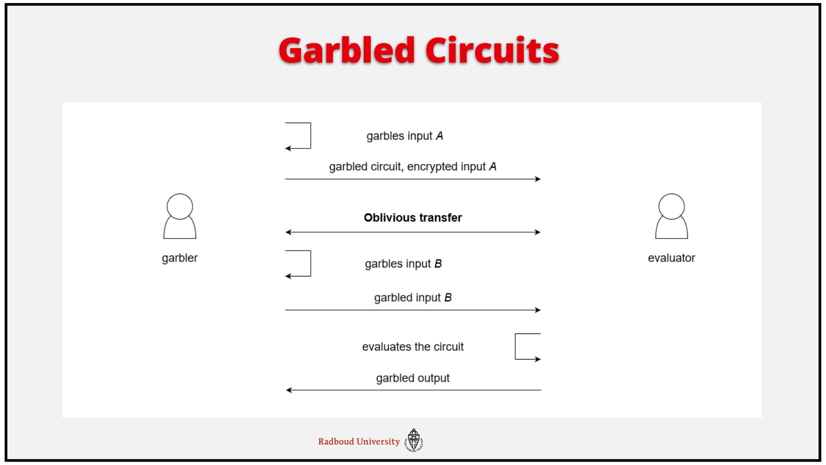

Garbled Circuits

garbler

evaluator

garbles input *A*

garbled circuit, encrypted input *A*

Oblivious transfer

garbles input *B*

garbled input *B*

evaluates the circuit

garbled output

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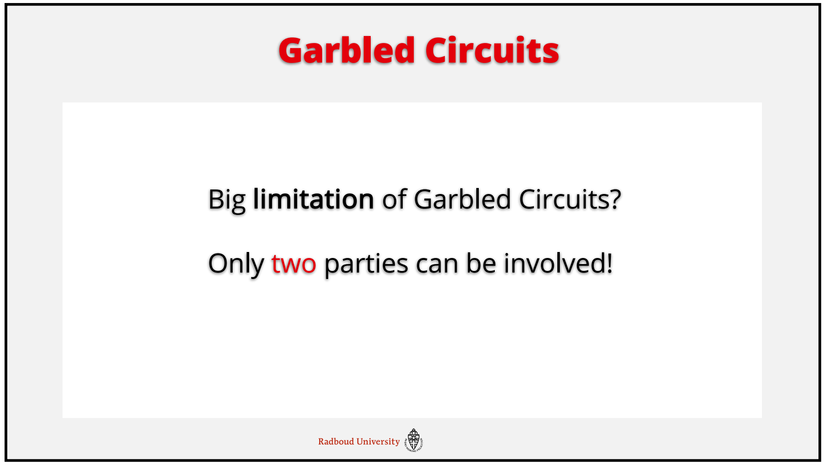

Garbled Circuits

Big **limitation** of Garbled Circuits?

Only two parties can be involved!

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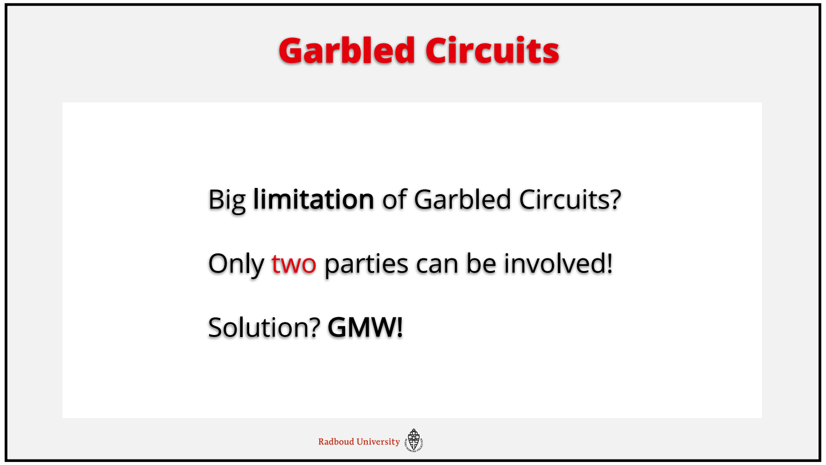

Garbled Circuits

Big **limitation** of Garbled Circuits?

Only two parties can be involved!

Solution? **GMW!**

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Goldreich, Micali and Wigderson

Solves the problem!

- Developed in 1987
- Designed for multiparty computation

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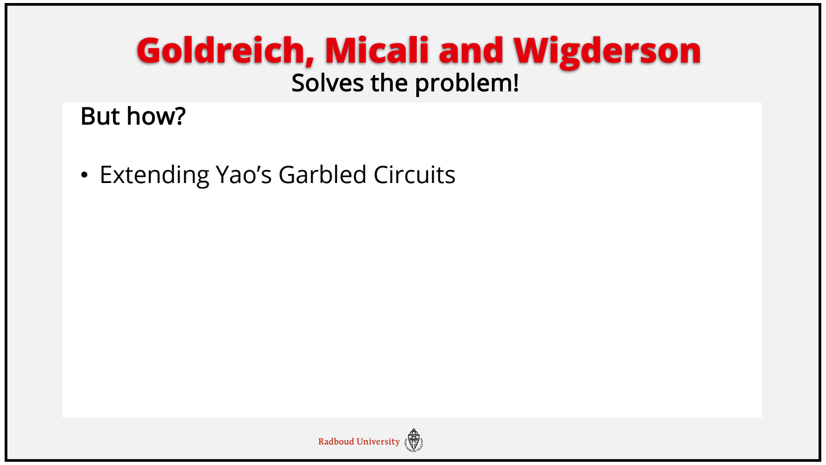

Goldreich, Micali and Wigderson

Solves the problem!

But how?

- Extending Yao's Garbled Circuits

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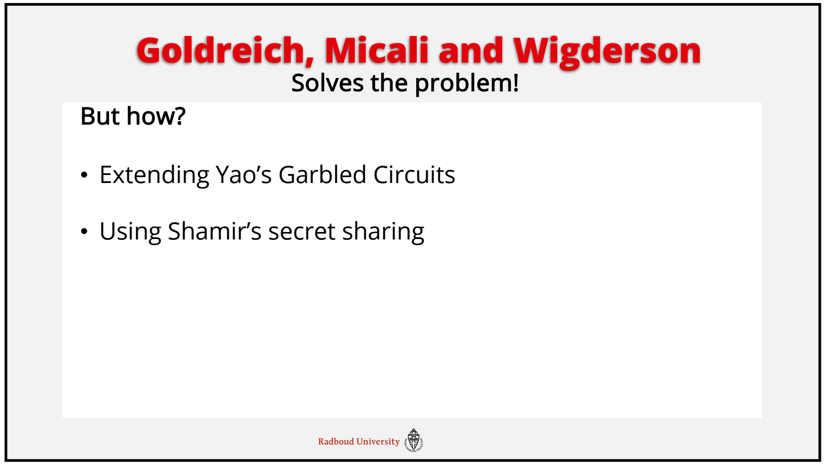

Goldreich, Micali and Wigderson

Solves the problem!

But how?

- Extending Yao's Garbled Circuits
- Using Shamir's secret sharing

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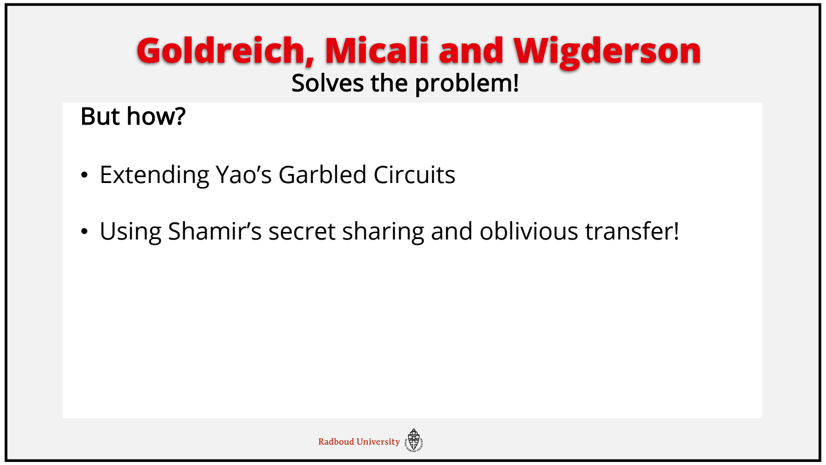

Goldreich, Micali and Wigderson

Solves the problem!

But how?

- Extending Yao's Garbled Circuits
- Using Shamir's secret sharing and oblivious transfer!

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Attacks

What do we need to protect?

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Attacks

What do we need to protect?

- Correctness
- Privacy

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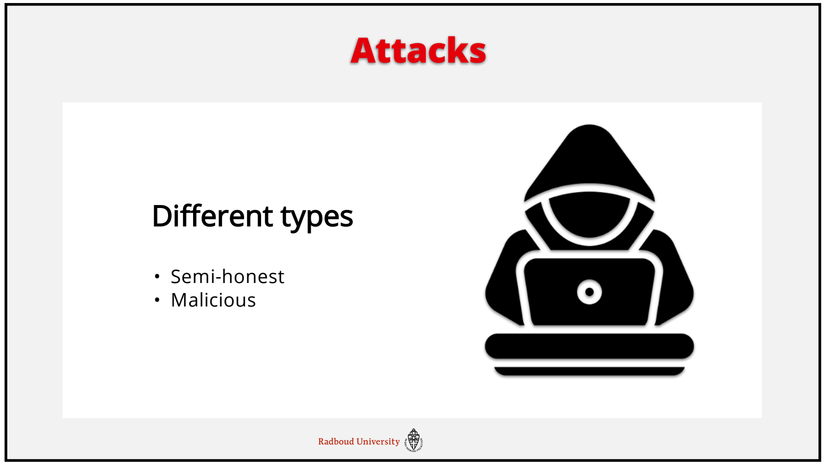

Attacks

Different types

- Semi-honest
- Malicious

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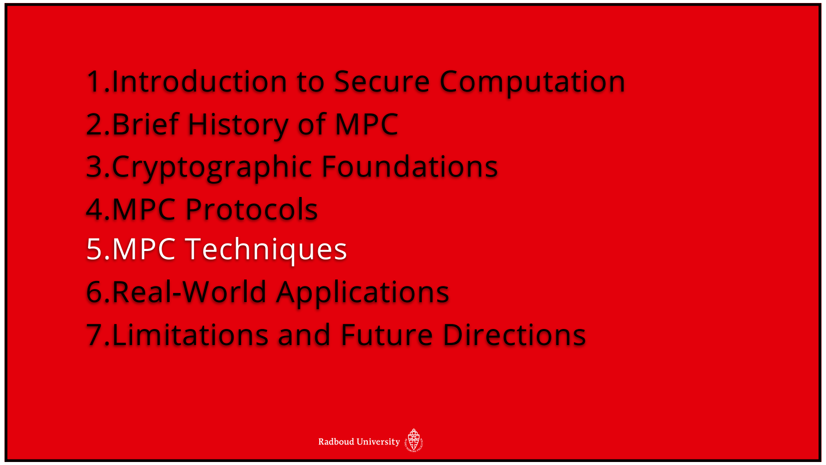

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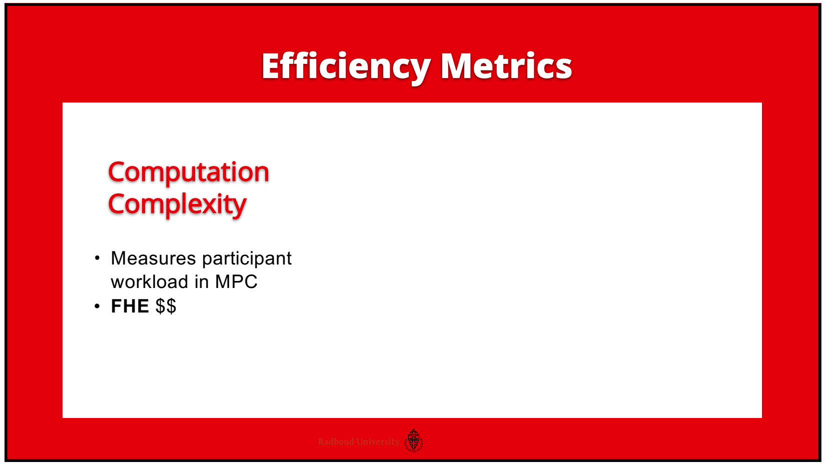

Efficiency Metrics

Computation Complexity

- Measures participant workload in MPC
- **FHE** $$

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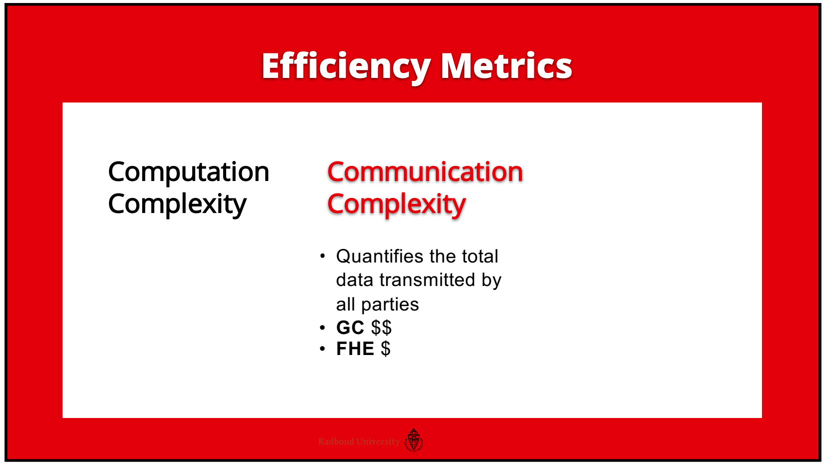

Efficiency Metrics

Computation Complexity

Communication Complexity

- Quantifies the total data transmitted by all parties
- **GC** $$
- **FHE** $

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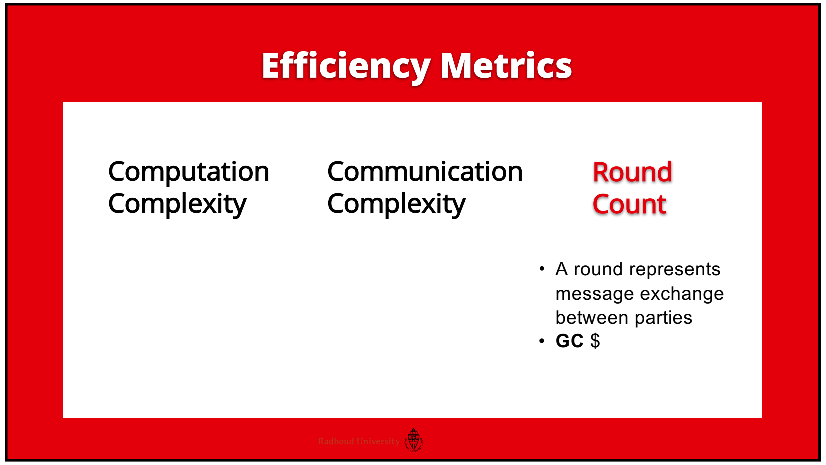

Efficiency Metrics

Computation Complexity

Communication Complexity

Round Count

- A round represents message exchange between parties
- **GC** $

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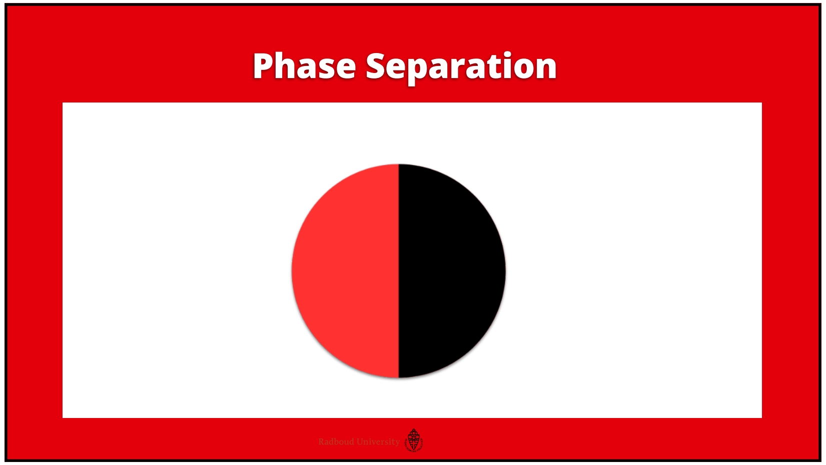

Phase Separation

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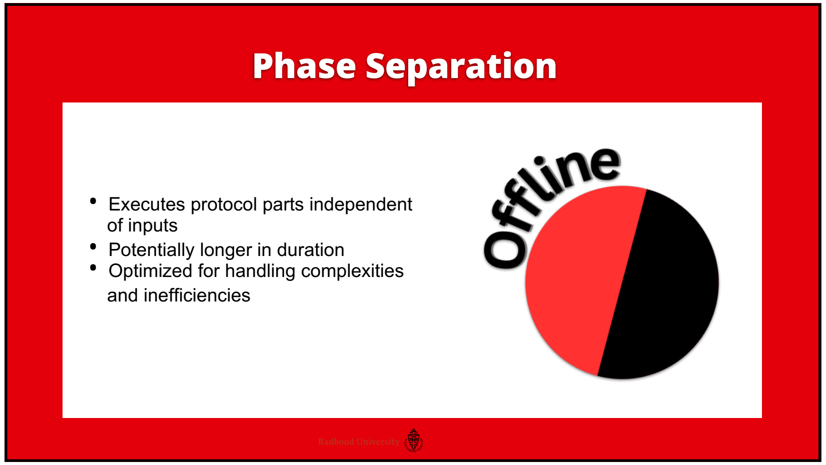

Phase Separation

- Executes protocol parts independent of inputs
- Potentially longer in duration
- Optimized for handling complexities and inefficiencies

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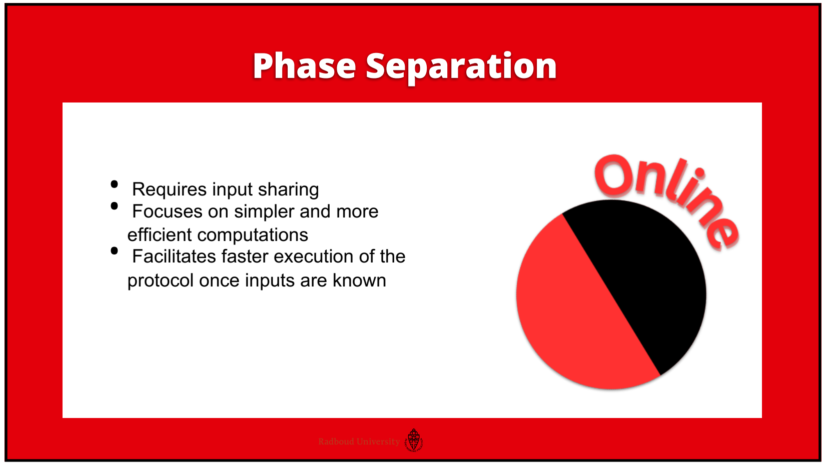

Phase Separation

- Requires input sharing
- Focuses on simpler and more efficient computations
- Facilitates faster execution of the protocol once inputs are known

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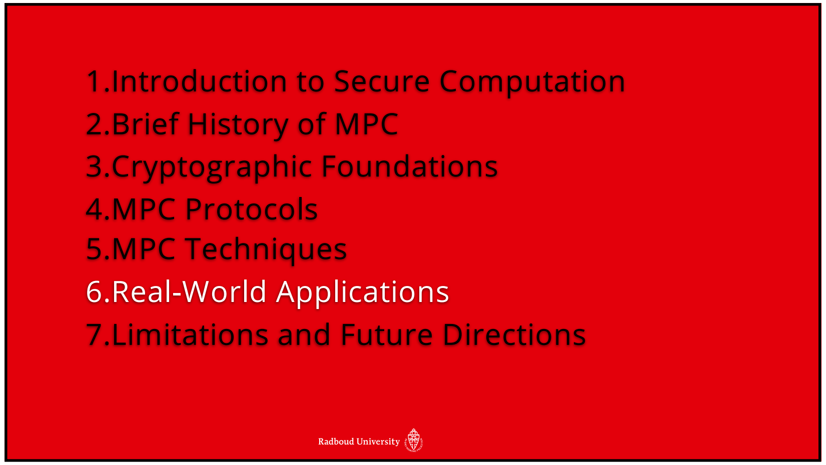

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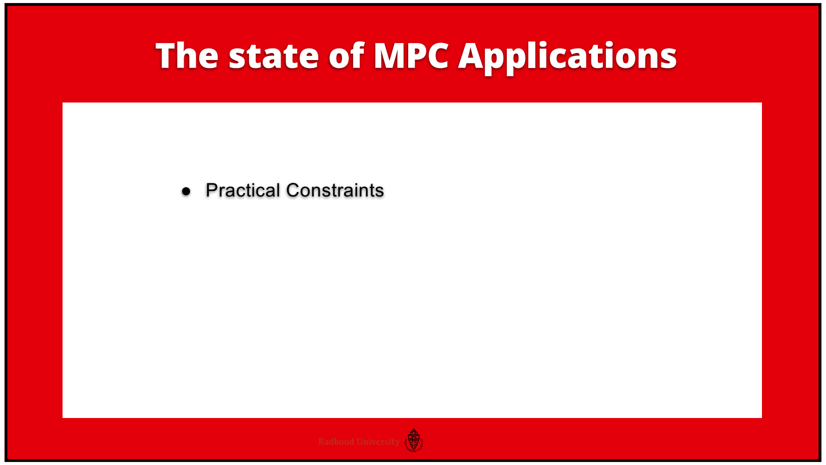

The state of MPC Applications

- Practical Constraints

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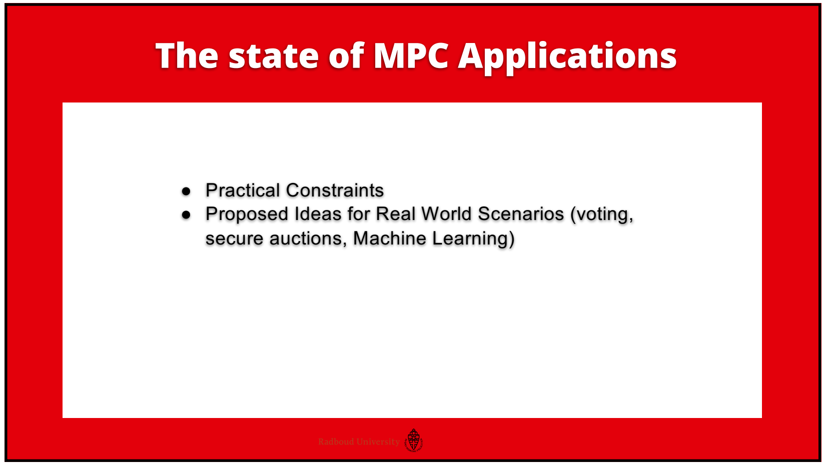

The state of MPC Applications

- Practical Constraints
- Proposed Ideas for Real World Scenarios (voting, secure auctions, Machine Learning)

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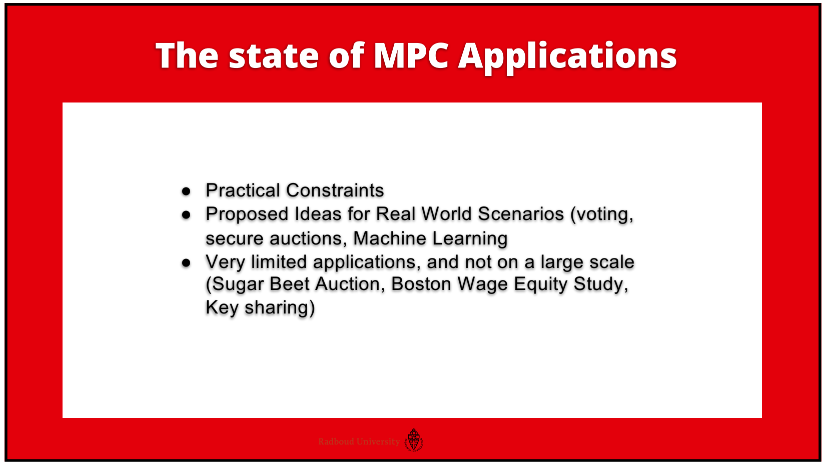

The state of MPC Applications

- Practical Constraints
- Proposed Ideas for Real World Scenarios (voting, secure auctions, Machine Learning
- Very limited applications, and not on a large scale (Sugar Beet Auction, Boston Wage Equity Study, Key sharing)

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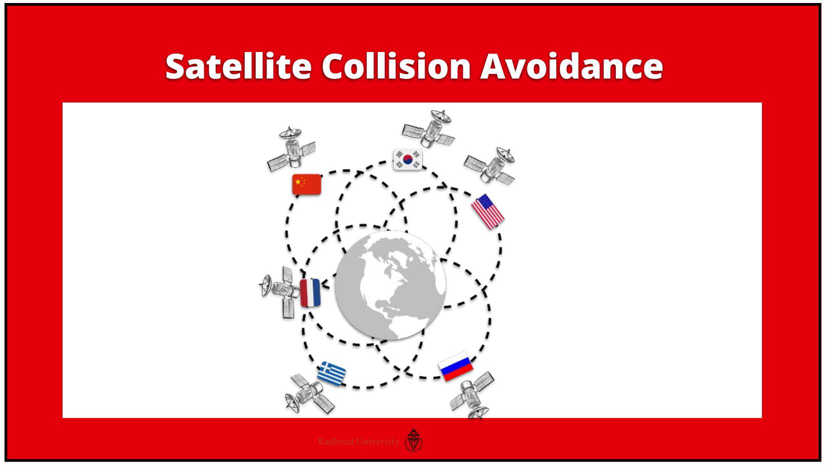

Satellite Collision Avoidance

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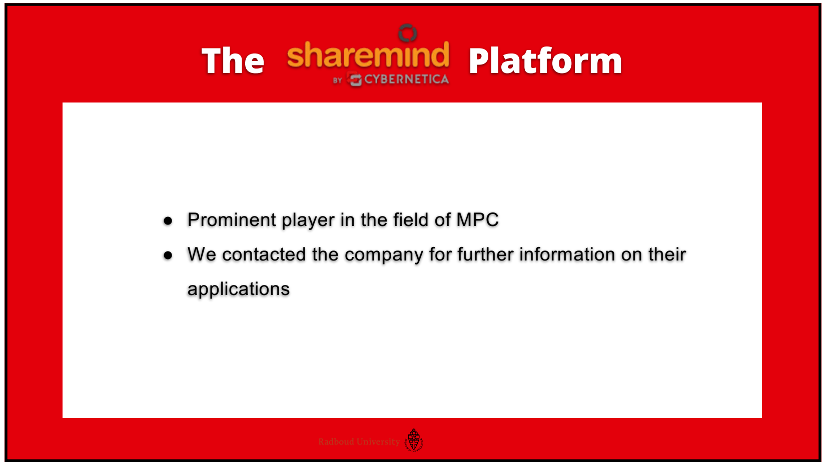

The sharemind BY CYBERNETICA Platform

- Prominent player in the field of MPC
- We contacted the company for further information on their applications

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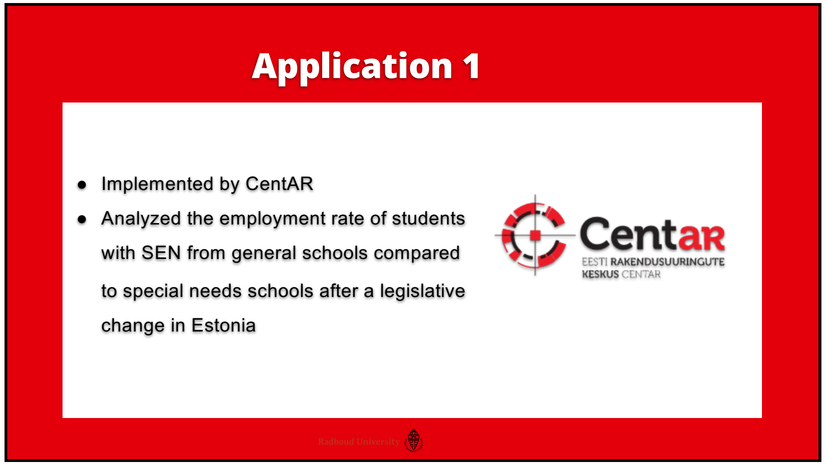

Application 1

- Implemented by CentAR
- Analyzed the employment rate of students with SEN from general schools compared to special needs schools after a legislative change in Estonia

Centar EESTI RAKENDUSUURINGUTE KESKUS CENTAR

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Application 2

- AssistOK and CAP Tulsa

@ssistOK.org
cap Tulsa
Helping Families Succeed
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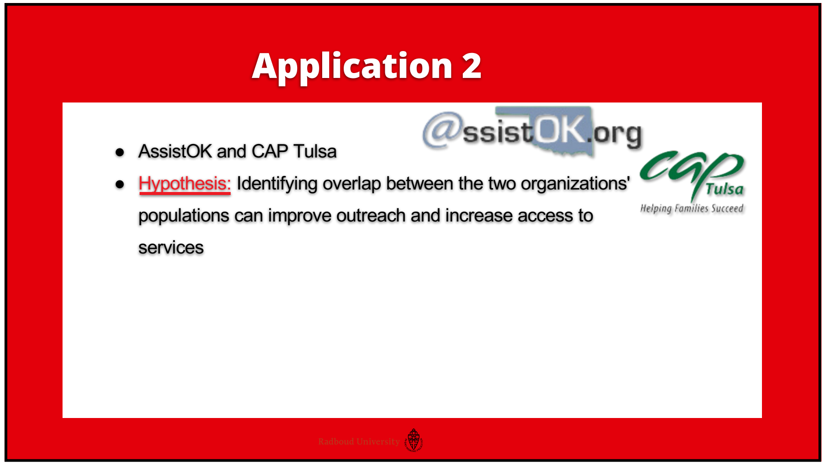

Application 2

- AssistOK and CAP Tulsa
- Hypothesis: Identifying overlap between the two organizations' populations can improve outreach and increase access to services

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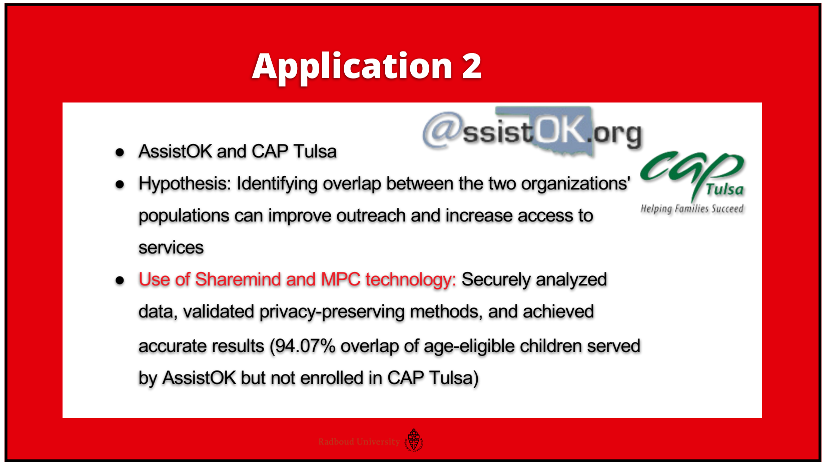

Application 2

- AssistOK and CAP Tulsa
- Hypothesis: Identifying overlap between the two organizations' populations can improve outreach and increase access to services
- Use of Sharemind and MPC technology: Securely analyzed data, validated privacy-preserving methods, and achieved accurate results (94.07% overlap of age-eligible children served by AssistOK but not enrolled in CAP Tulsa)

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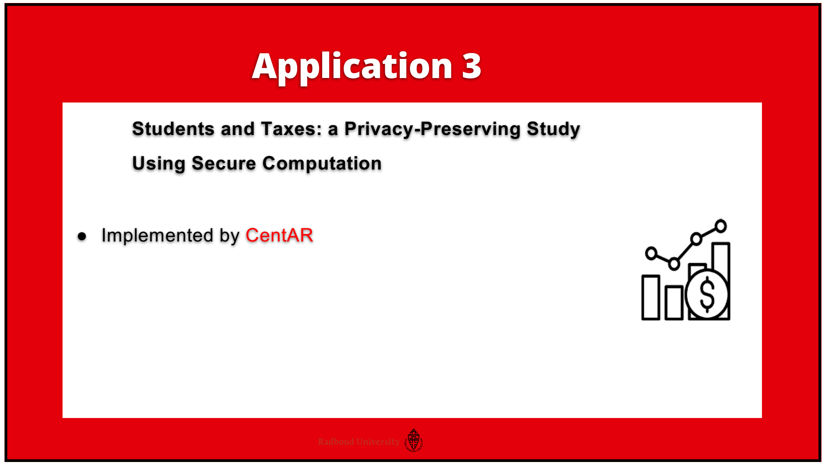

Application 3

Students and Taxes: a Privacy-Preserving Study Using Secure Computation

- Implemented by CentAR

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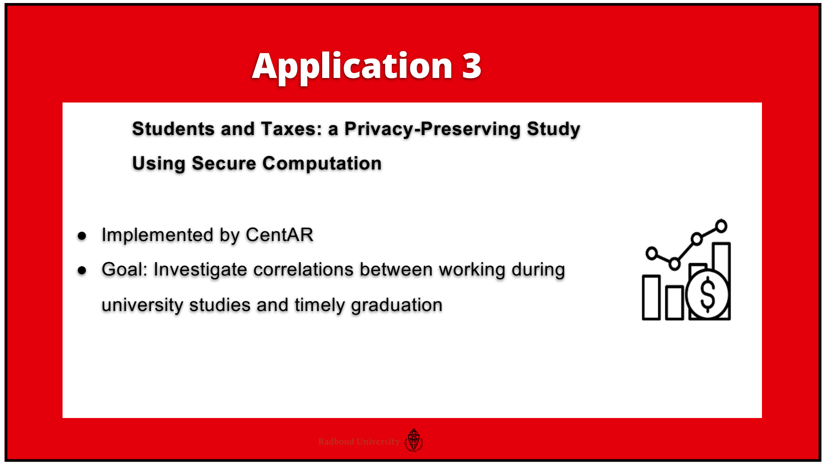

Application 3

Students and Taxes: a Privacy-Preserving Study Using Secure Computation

- Implemented by CentAR
- Goal: Investigate correlations between working during university studies and timely graduation

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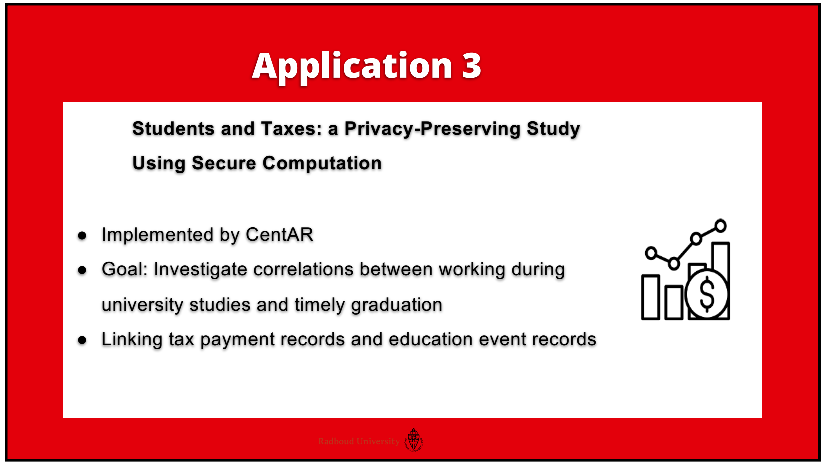

Application 3

Students and Taxes: a Privacy-Preserving Study Using Secure Computation

- Implemented by CentAR
- Goal: Investigate correlations between working during university studies and timely graduation
- Linking tax payment records and education event records

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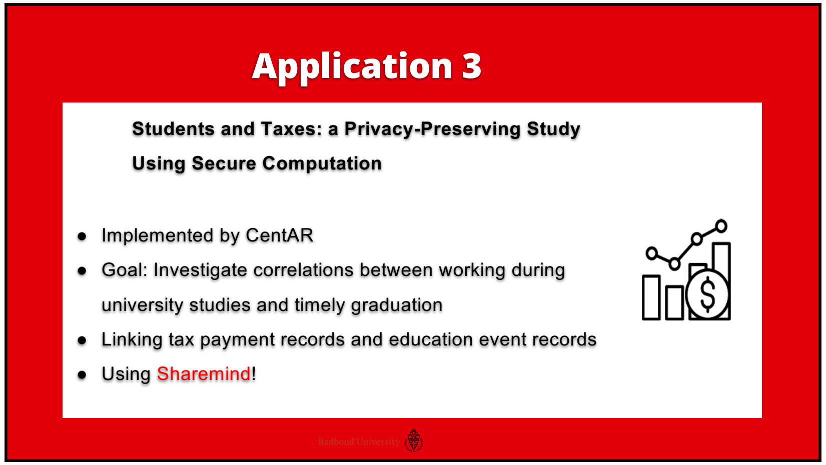

Application 3

Students and Taxes: a Privacy-Preserving Study Using Secure Computation

- Implemented by CentAR
- Goal: Investigate correlations between working during university studies and timely graduation
- Linking tax payment records and education event records
- Using Sharemind!

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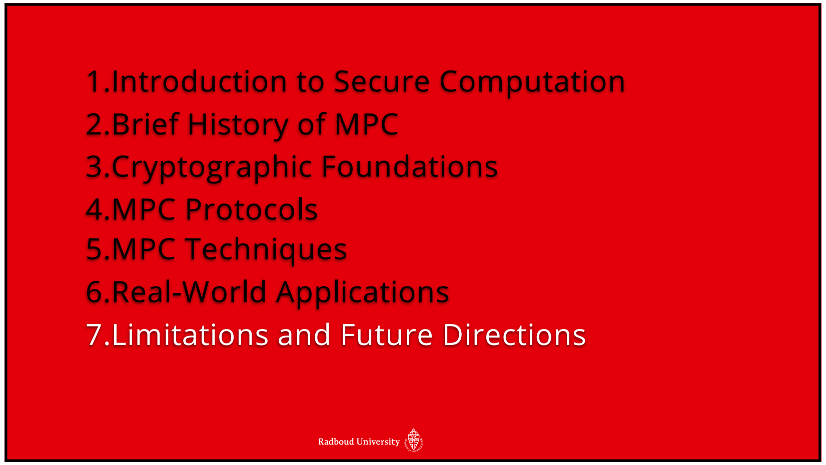

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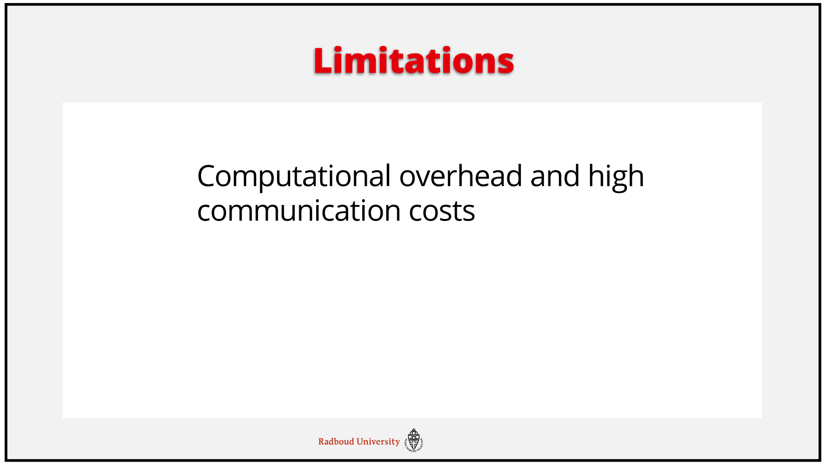

Limitations

Computational overhead and high communication costs

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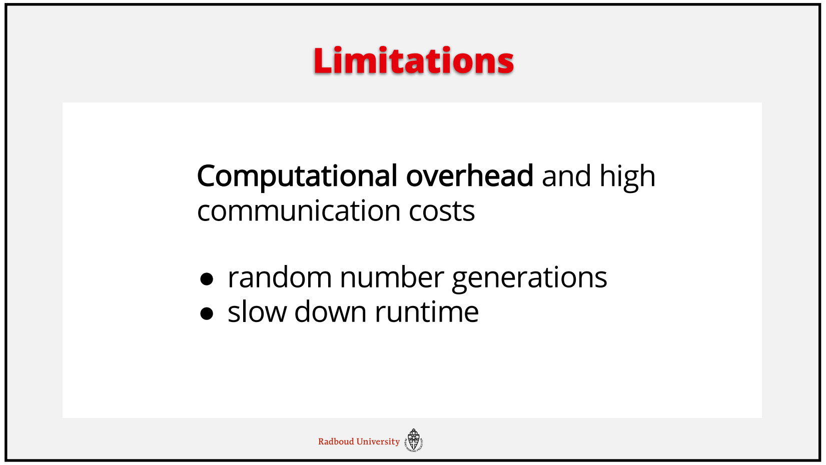

Limitations

Computational overhead and high communication costs

- random number generations
- slow down runtime

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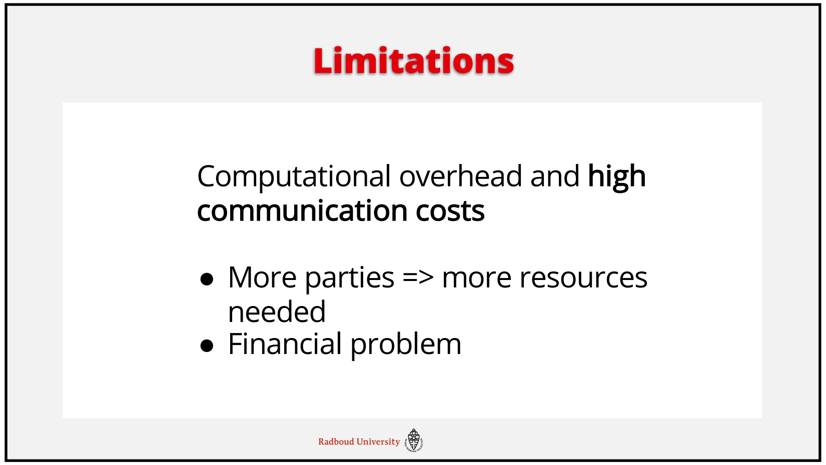

Limitations

Computational overhead and **high communication costs**

- More parties => more resources needed
- Financial problem

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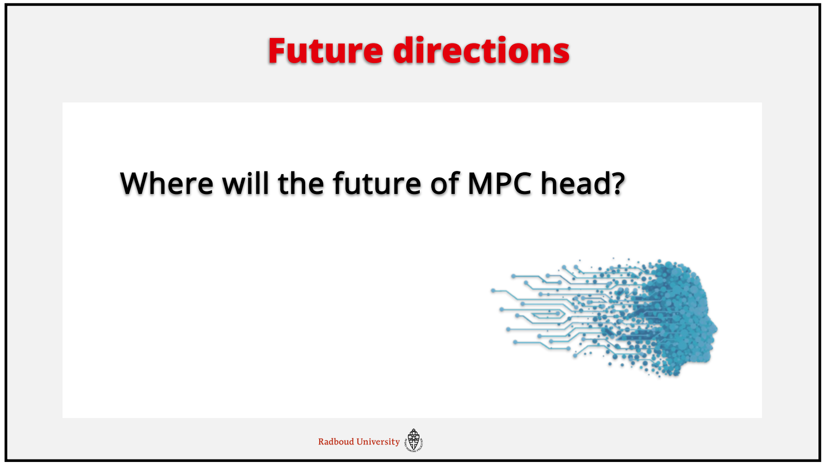

Future directions

Where will the future of MPC head?

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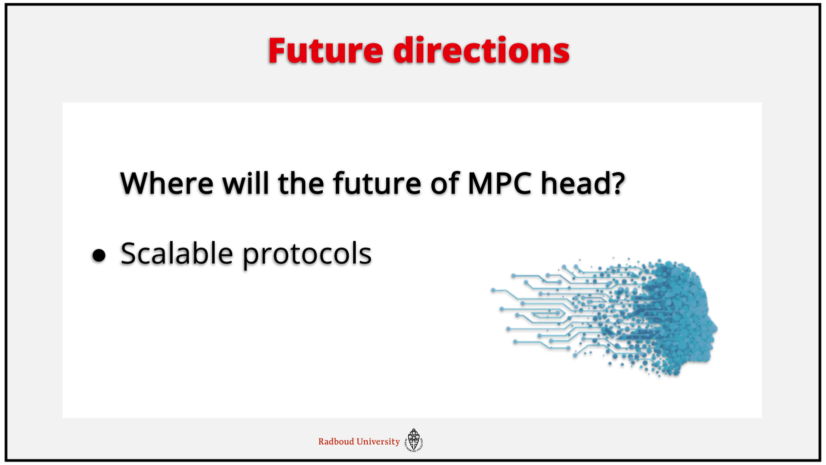

Future directions

Where will the future of MPC head?

- Scalable protocols

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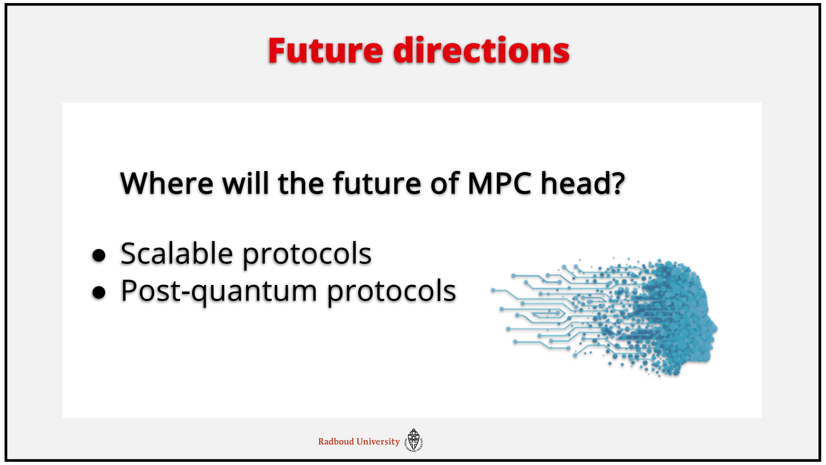

Future directions

Where will the future of MPC head?

- Scalable protocols
- Post-quantum protocols

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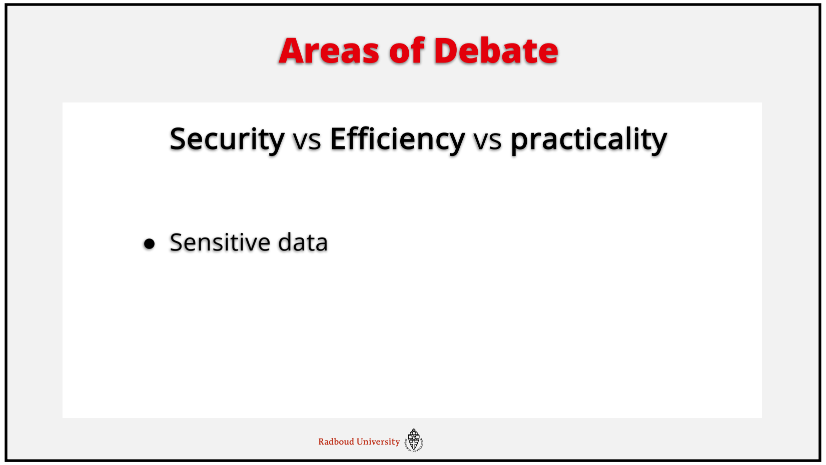

Areas of Debate

Security vs Efficiency vs practicality

- Sensitive data

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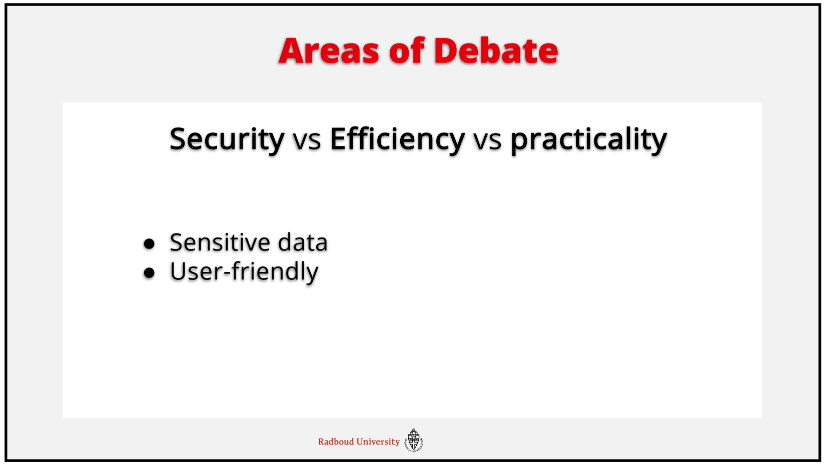

Areas of Debate

Security vs Efficiency vs practicality

- Sensitive data
- User-friendly

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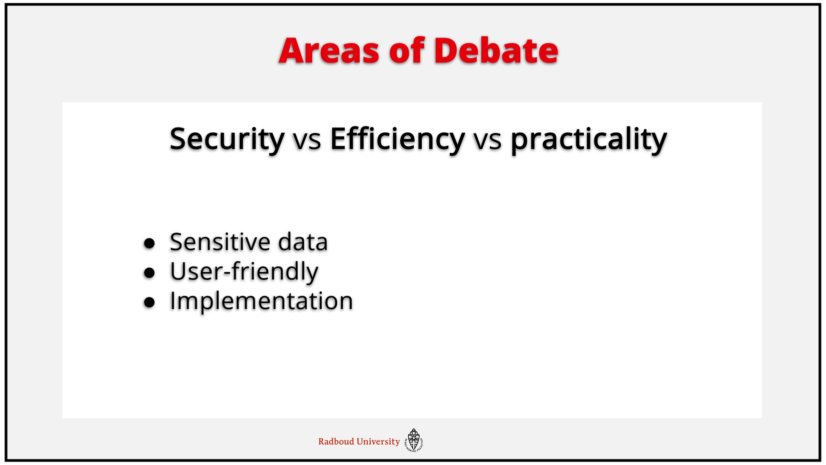

Areas of Debate

Security vs Efficiency vs practicality

- Sensitive data
- User-friendly
- Implementation

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So, what do YOU think?

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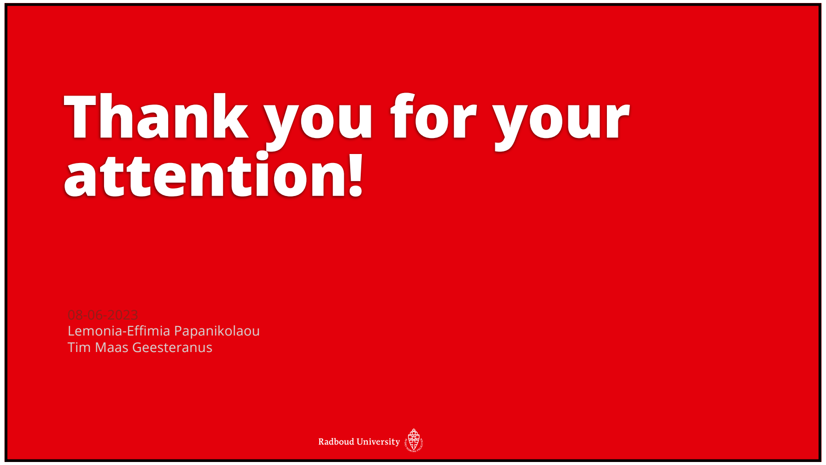

Thank you for your attention!

08-06-2023
Lemonia-Effimia Papanikolaou
Tim Maas Geesteranus

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