ÉCOLE THÉMATIQUE CNRS
COST ACTION SUMMER SCHOOL

An introduction to electronic voting
Application to single transferable vote

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Interdisciplinary Analysis of Voting Rules

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Outline

- Context
- Problematic / Security issues
- Some challenges in Electronic Voting
- Introduction to public-key cryptography (short and non-technical)
- Recent breakthroughs in electronic voting
- Conclusion

1 Context

Definition

- E-election or e-referendum: a political election or referendum in which electronic means are used in one or more stages.

- E-voting: an e-election or e-referendum that involves the use of electronic means in at least the casting of the vote (entering the vote in the ballot box)
  - Recommendation of the Council of Europe: «Legal,Operational and Technical Standards for E-voting» , 30 September 2004

- The other phases (registration on the electoral roll, identification/authentication of elligible voters) can be done as in traditional paper-ballot elections or by using electronic means

Classification

- Supervised voting (off-line voting)
  - supervised physically by independent electoral authorities
  - voting machines located at polling stations (not connected)

- Hybrid Voting
  - supervised physically by election officials
  - Internet connected voting machines

- Remote voting (on-line voting)
  - unsupervised by election officials
  - (typically) through Internet using a personal computer or a mobile phone

Arguments (1)

- Reducing the overall cost to the electoral authorities of conducting an election or referendum
- Delivering voting results reliably and more quickly
- Increasing voter turnout by providing additional voting channels
- Increasing the number of elections
- Widening access to the voting process for voters with disabilities

- Bringing voting in line with new developments in society and increasing use of new technologies

Arguments (2)

- Handling different kind of voting methods (Single Transferable Vote, Condorcet, …)

Rank any number of options in your order of preference	
1	Nicolas
2	Ségolène
	~~François~~

Rank any number of options in your order of preference	
2	Nicolas
1	François
3	Ségolène

- Manual counting would be cumbersome and prone to errors
- Not a secure voting system: vulnerable to a so-called "Sicilian attack" (coercion attack)
- STV used in several countries: Ireland, Scotland, Australia, etc.

E-voting in France

- Supervised voting 
  - allowed for national elections since 1969 - decree n° 69-419 of 10 may 1969
  - used in 2005 (European Referendum) and in 2007 (presidential election)
- Hybrid voting 
  - might be allowed in the forthcoming years for national elections
- Remote voting 
  - similar to postal voting (forbidden since1975)
  - allowed, since 2003, for specific elections such as industrial tribunal elections

E-voting in other countries

- Supervised voting 
  - Belgium, Brazil, US,…
- Hybrid voting 
  - Italy : for a local election (Ladispoli)
- Internet voting 
  - Estonia: for major elections in 2005 (municipal), 2007 (parliamentary), 2009 (municipal) and 2011 (parliamentary) .
  - Korea: planned for presidential elections in the forthcoming years
  - Switzerland: test projects in several cantons (Aargau, Geneva, Neuchâtel and Zürich)
  - Norway: experiments in 2011 and 2013 for local and national elections

Current voting machines

- Several systems, only 3 have been approved in France:
  - iVotronic (ES&S – Datamatique)
  - Machine à voter v2.07 (Nedap – France Election)
  - Point & Vote (Indra Systemas)

- Objections
  - opaque systems (not open source)
  - similar to proxy voting (where a proxy form is given to a voting machine)
  - accuracy of the outcome of the election

- Several attacks have been reported
  - Netherland: hackers showed how to tamper with Nedap voting machines
  - Arkansas : a candidate received no vote (although he voted for himself)
  - Belgium: number of votes **>>** number of registered voters

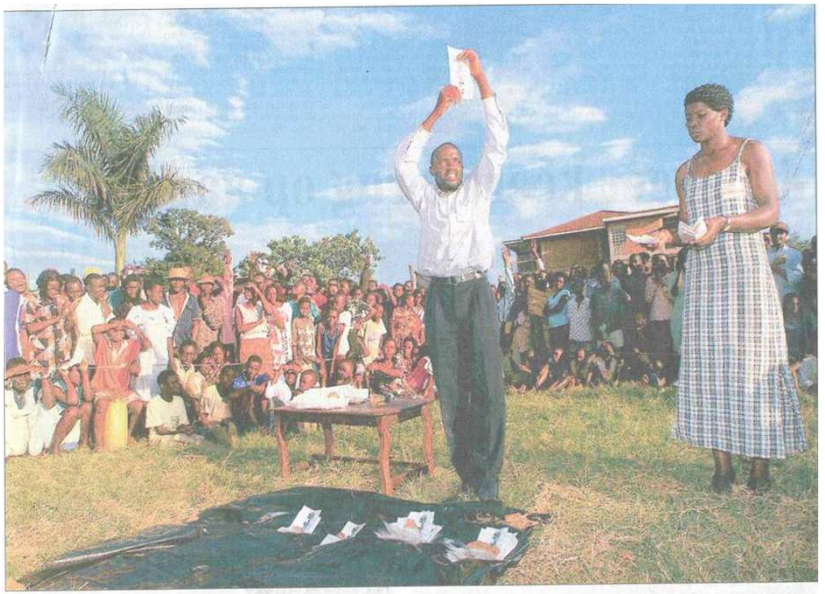
Security requirements (1)

- Eligibility
  - only legitimate voters can vote, and only once
- Ballot secrecy
  - No outside observer can determine for whom a voter voted
  - Perfect ballot secrecy = everlasting secrecy
- Receipt-freeness
  - A voter cannot prove *after the election* how she voted
  - prohibit proof of vote

- Coercion-resistance
  - no party should be able to force another party to vote in a certain way or abstain from voting

Security requirements (2)

- Individual verifiability
  - The voter can verify that his ballot has been cast /counted
- Universal verifiability
  - Any interested party can verify that the tally is correctly computed from votes that were cast by legitimate voters
- Fairness
  - No partial results are known before the election is closed



Het volk controleert de telling

Een functionaris van een Ugandees stembureau toont een stembiljet tijdens het tellen van de stemmen voor een nieuwe president. De huidige president Museveni wordt hoogstwaarschijnlijk herkozen. Verslag op pagina 5.

FOTO JEAN-MARC BOUJU/AP

Some challenges in e-voting

- How to combine (perfect) *secrecy* and (universal) *verifiability* ? (Challenge A)

- How to detect misbehaving voting machines? (Challenge B)
  - “It's not the people who vote that count. It's the people who count the votes” (Joseph Stalin)
  - What you see is what you vote for

- How to combine *remote* voting and *coercion-free* voting ? (Challenge C)

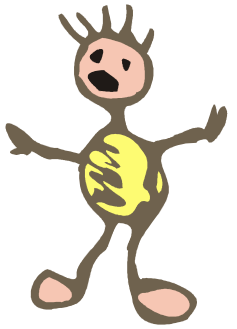
Challenge A

- How to combine (perfect) *secrecy* and (universal) *verifiability* ?
- Perfect = unconditional = everlasting
- *Easy* to solve if secrecy is not required to be perfect (e.g. use *homomorphic encryption*)
- *Impossible* to solve (in a practical environment) if secrecy is required to be perfect (Chevallier-Mames/Fouque/Pointcheval/Stern/Traoré*)

* On Some Incompatible Properties of Voting Schemes, Benoît Chevallier-Mames, Pierre-Alain Fouque, David Pointcheval, Julien Stern, Jacques Traoré, Towards Trustworthy Elections, Springer Verlag, 2010.

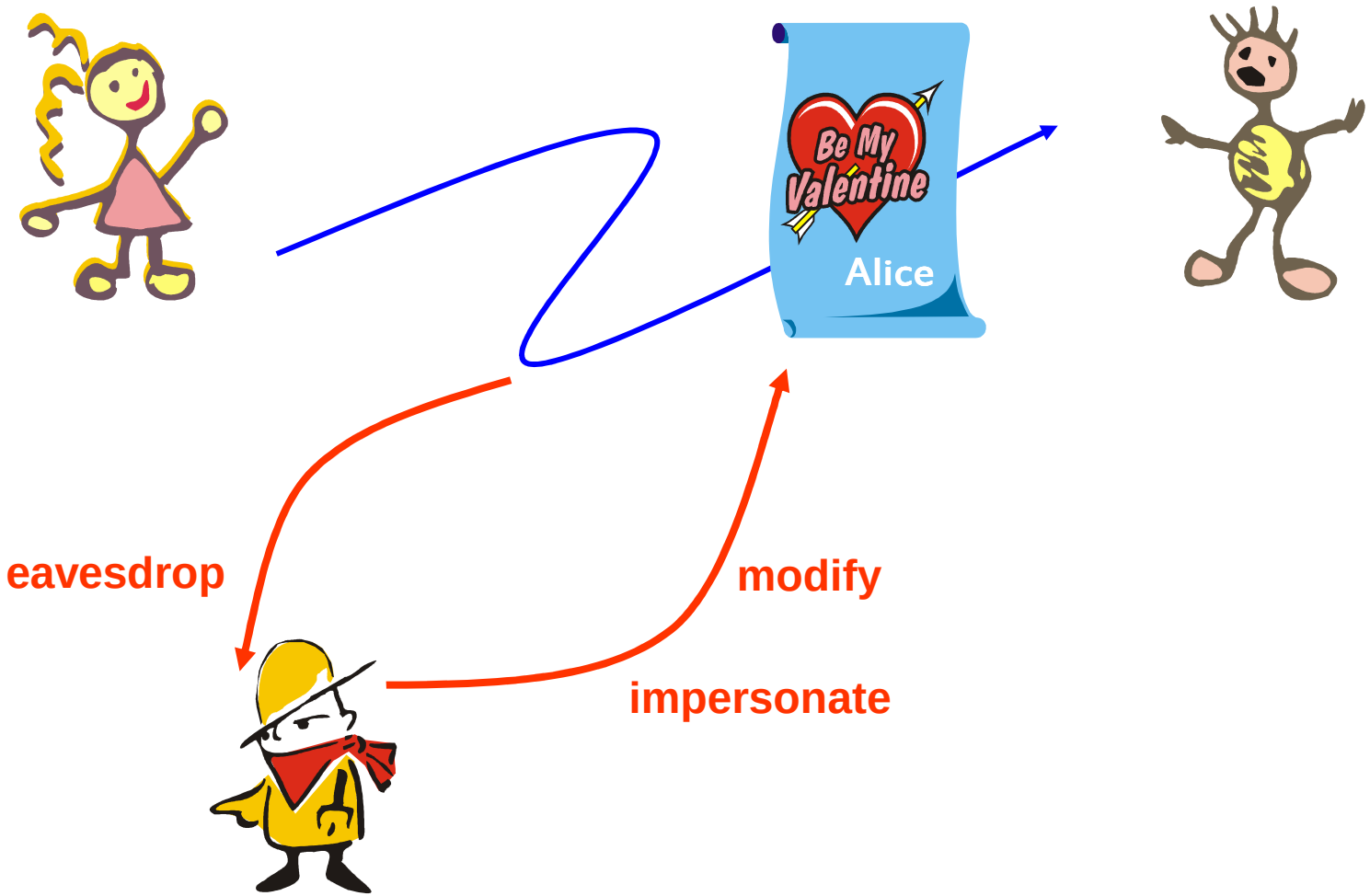
2 Cryptography

Definitions

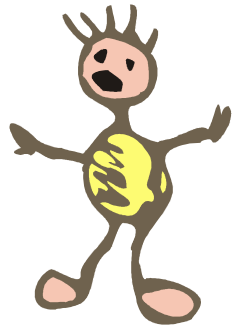


- crypto = κρυπτός = “hidden, secret”
- **cryptography** = **cryptology** = « science of secret » or « science of trust »
- Crossroads between art, science, research and industry, mathematics and computer science

Attacks

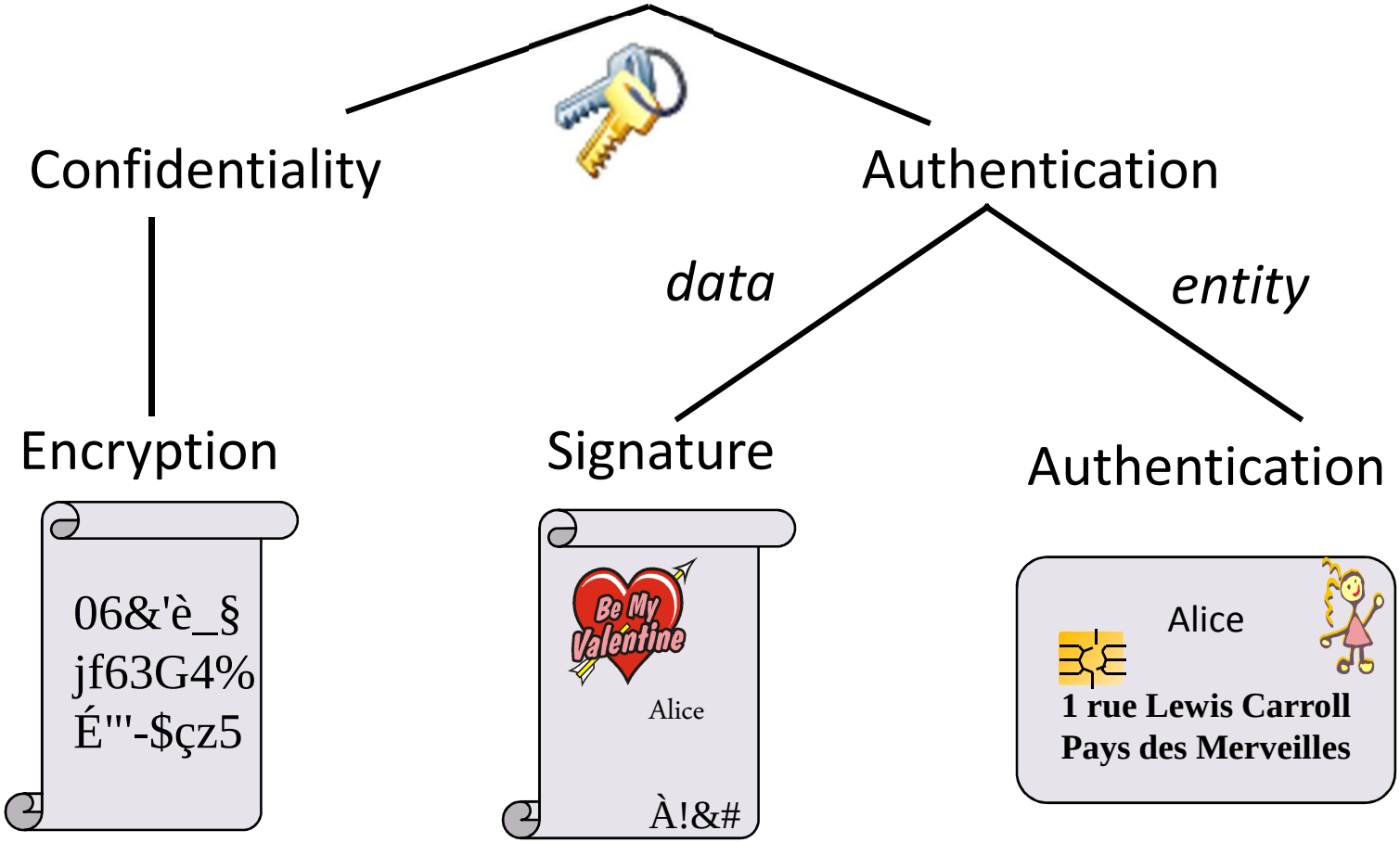


Main goals of cryptography

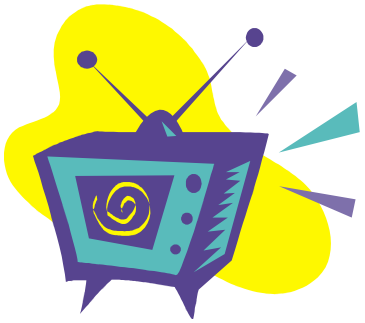


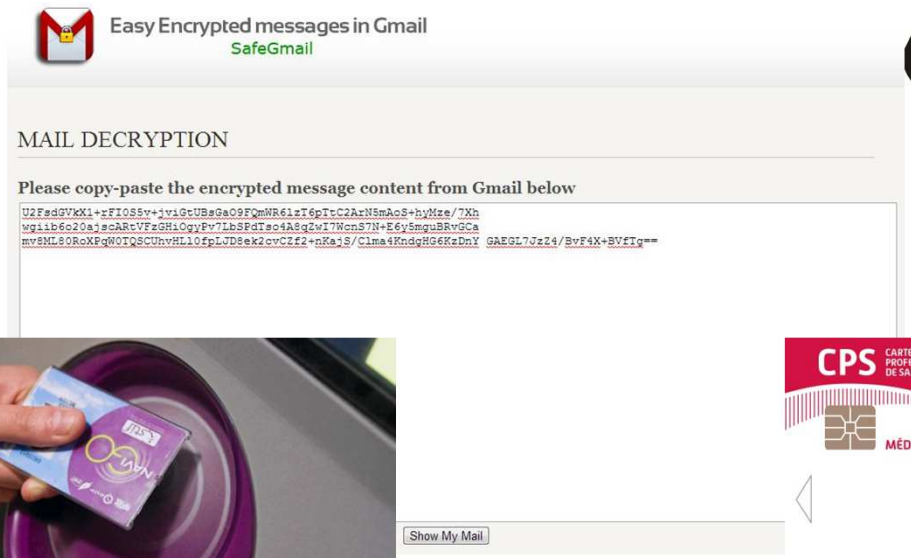
- data confidentiality (privacy)
- data/entity authentication (it came from where it claims)
- data integrity (it has not been modified on the way)

Cryptography



Cryptography is everywhere…





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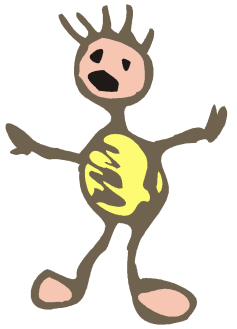
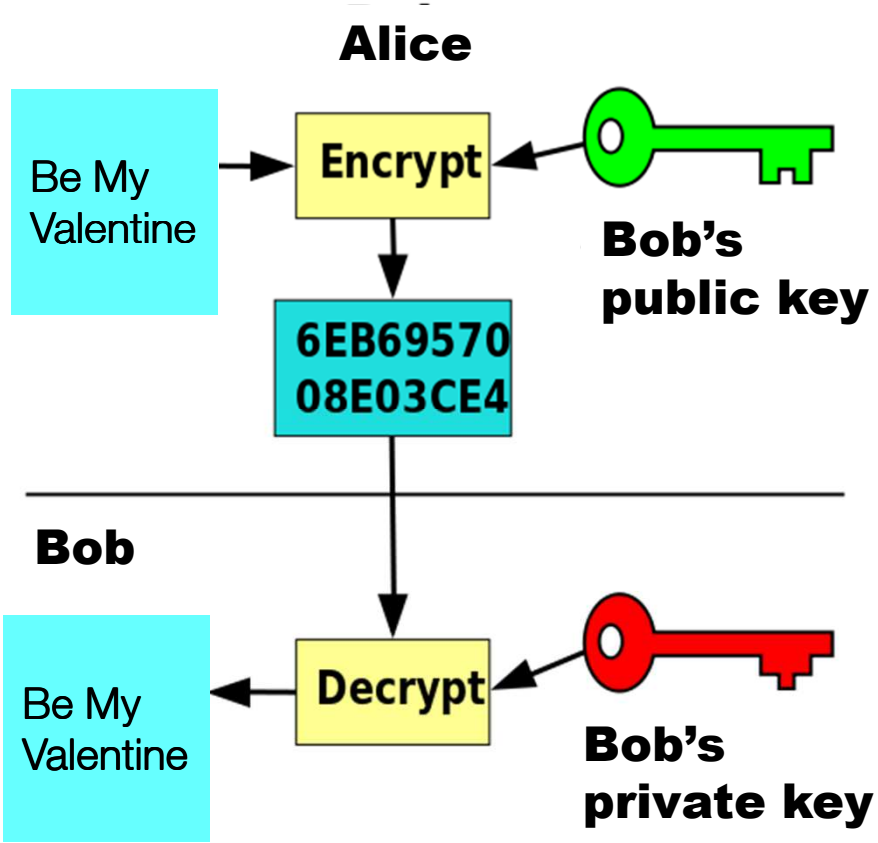
3 Public-Key Cryptography

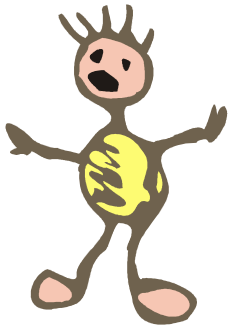
Principle



- **asymmetric** cryptography = **public-key** cryptography
  (discovered – officially – in 1976)



How does it works?

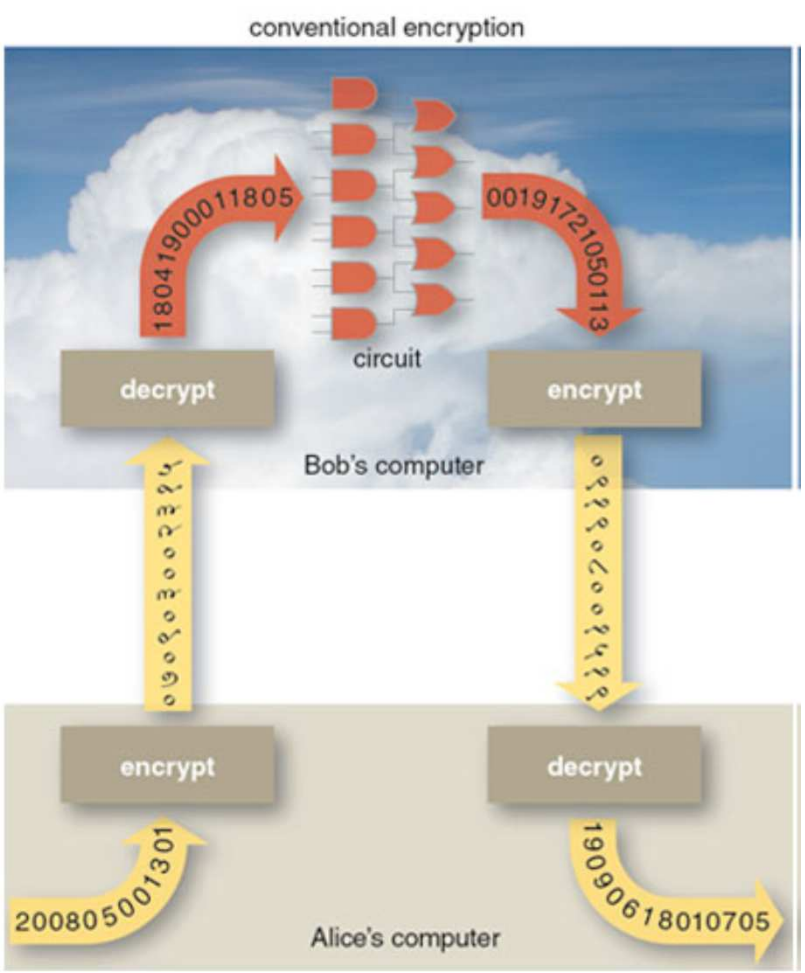


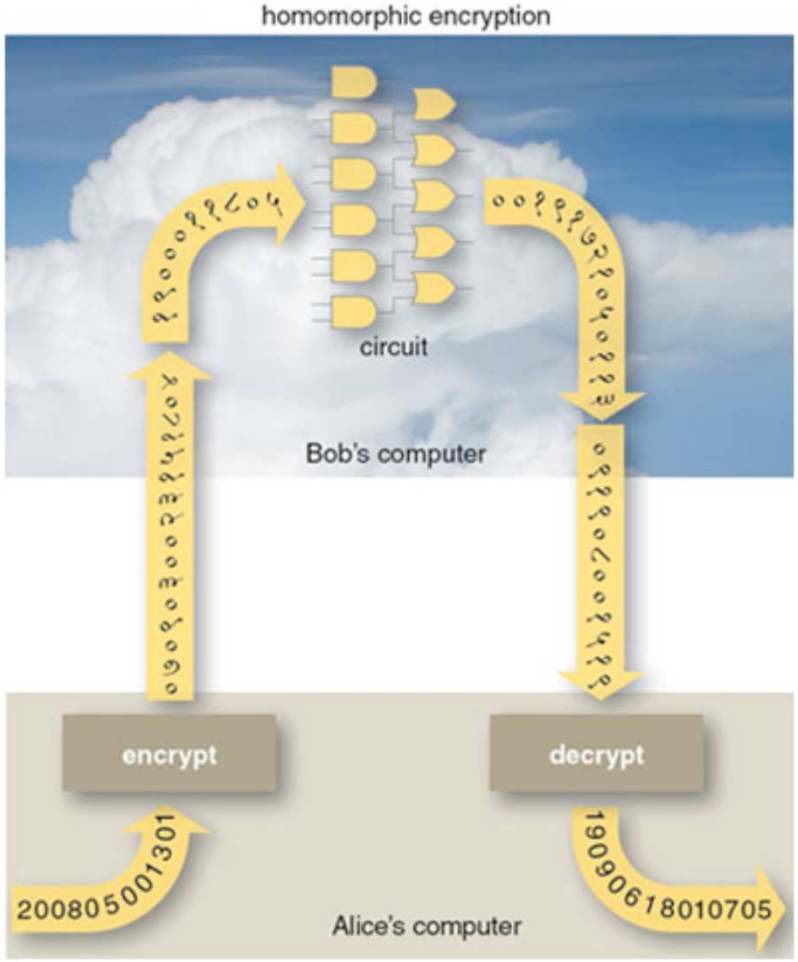
- Asymmetric cryptography exists because “asymmetric” problems exist
- Example (integer factorization) :
  - it is easy to compute the product of two large (prime) integers, however…
  - … it is hard, given only the product, to find its factorization (retrieve the two prime integers)

100 895 598 169 = ... × ..... ?

4 Computing on Encrypted Data

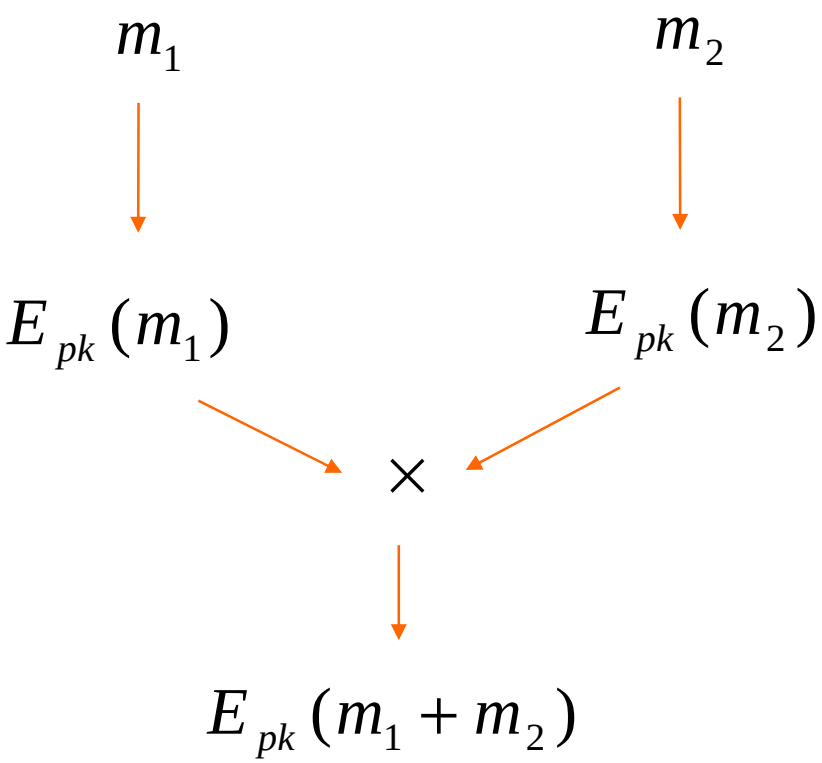
What is homomorphic encryption?





Homomorphic Encryption in Practice

- Application to e-voting



Real-life applications of Homomorphic Encryption

- Secret-ballot internet voting
- Supported computation: addition
- The decryption key is shared among the talliers:

- Referendum case: “yes” = 1 and “no” = 0,
  - Each voter encrypts her vote using the talliers’ public keys.
  - The voting center computes an encryption of the sum of the votes thanks to the properties of the homomorphic encryption scheme.
  - The talliers decrypt this ciphertext and obtain the outcome of the election.
  - No individual vote is revealed!

5 Challenge B

Challenge B: How to detect misbehaving voting machines

End-to-End verifiability: a voter can verify that

- cast-as-intended: her choice was not modified by the voting machine
- recorded-as-cast: her ballot was received the way she cast it
- tallied as recorded: her ballot count as received

Voting machine with untrusted software


VOTE VERIFICATION RECEIPT

BALLOT #48763

----Begin Ballot Record----

OSWP/BSeORkNTeaKs7Z2XGL1LZRiTOJ1

-----End Ballot Record-----

Q1 President

>>>>> XP48 M2 <<<<<

Jones 1LM

Smith RS5

Martinez ZVJ

Q2 Bond Levy

>>>>>> A9T7 <<<<<<

Yes P4T

No 2DP

-------Begin Signature-------

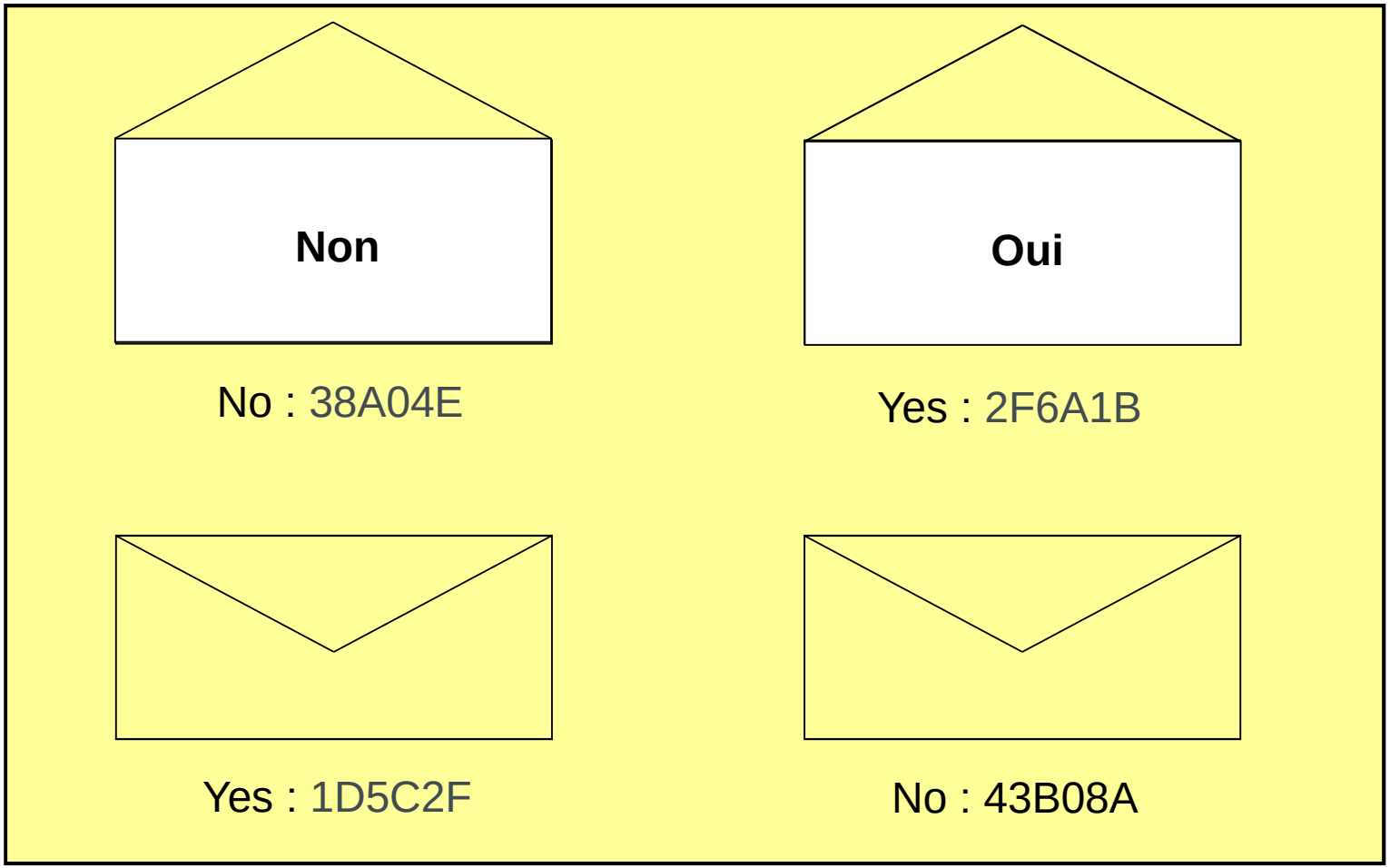
nD3BWBFUQwHFXfMhXdAaIbi3fMXYWBBJ

--------End Signature--------

PLEASE KEEP THIS RECEIPT TO VERIFY YOUR BALLOT ONLINE.

Vote Verification ticket

Cast as Intended



Ticket
38A04E
2F6A1B
1D5C2F
43B08A

6 Challenge C

Challenge C

- How to combine *on-line* and *coercion-free* voting ? (Araujo-Foule-Traoré)*

- Basic ingredients
  - A ballot may be valid or not
  - A coercer cannot decide if a ballot is valid or not
  - A voter can vote more than once

- Basic idea
  - To mislead a coercer, the voter sends invalid ballot(s) as long as he is coerced, and a valid ballot as soon as he is not coerced
  - It suffices that the voter finds a window-time during which he is not coerced

* A Practical and Secure Coercion-Resistant Scheme for Internet Voting, Roberto Araujo, Sébastien Foule, Jacques Traoré, Towards Trustworthy Elections, Springer Verlag, 2010.

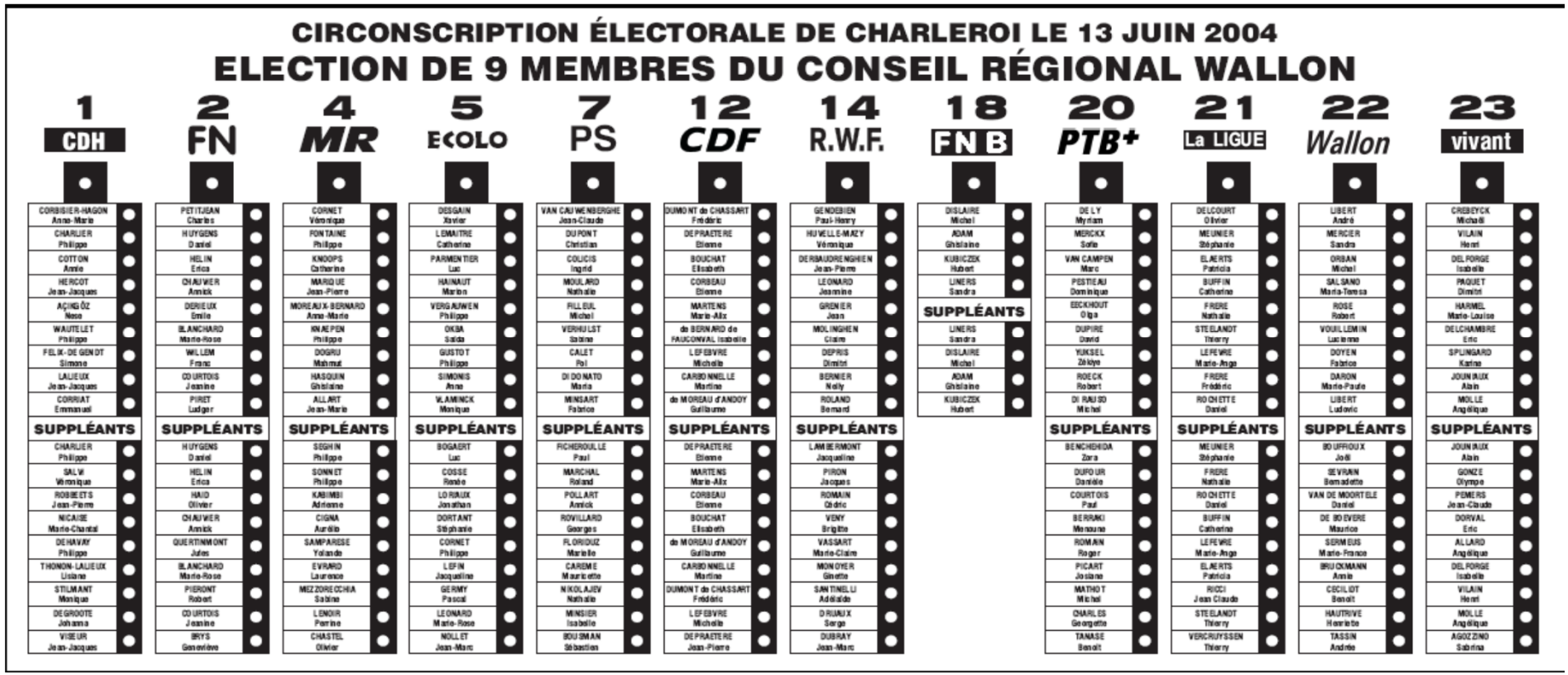
Conclusion

- E-voting is a true reality in several countries
  - Brazil, Estonia, United States, etc.
  - also in France (presidential election in 2007)

- Commercial e-voting solutions offer very poor security guarantees
- In spite of the impossibility result, there is some hope that a convenient (secure/practical) voting system exists one day, even for remote voting.

7 Annex

Preferential Voting



CIRCONSCRIPTION ÉLECTORALE DE CHARLEROI LE 13 JUIN 2004

ELECTION DE 9 MEMBRES DU CONSEIL RÉGIONAL WALLON

1 CDH	2 FN	4 MR	5 ECOLO	7 PS	12 CDF	14 R.W.F.	18 FN B	20 PTB+	21 La LIGUE	22 Wallon	23 vivant
CORBISIER-HAGON Anne-Marie	PETITJEAN Charles	CORNET Véronique	DESGAIN Xavier	VAN CAUWENBERGHE Jean-Claude	DUMONT de CHASSART Frédéric	GENDEBIEN Paul-Henry	DISLAIRE Michel	DE LY Myriam	DELCOURT Olivier	LIBERT André	CREBEYCK Michaël
CHARLIER Philippe	HUYGENS Daniel	FONTAINE Philippe	LEMAITRE Catherine	DUPONT Christian	DEPRAETERE Etienne	HUWELLE-MAZY Véronique	ADAM Ghislaine	MERCKX Sofie	MEUNIER Stéphanie	MERCIER Sandra	VILAIN Henri
COTTON Annie	HELIN Erica	KNOOPS Catherine	PARMENTIER Luc	COLICIS Ingrid	BOUCHAT Elisabeth	DERBAUDRENGHIEN Jean-Pierre	KUBICZEK Hubert	VAN CAMPEN Marc	ELAERTS Patricia	ORBAN Michel	DEL FORGE Isabelle
HERICOT Jean-Jacques	CHAUVIER Annick	MARIQUE Jean-Pierre	HAINAUT Marion	MOULARD Nathalie	CORBEAU Etienne	LEONARD Jeannine	LINERS Sandra	PESTIEAU Dominique	BUFFIN Catherine	SALSANO Maria-Teresa	PAQUET Dimitri
AÇIKGÖZ Nese	DERIEUX Emile	MOREAUX-BERNARD Anne-Marie	VERGAUWEN Philippe	FILLEUL Michel	MARTENS Marie-Alix	GRENIER Jean		ECKHOUT Olga	FRERE Nathalie	ROSE Robert	HARMEL Marie-Louise
WAUTELET Philippe	BLANCHARD Marie-Rose	KNAEPEN Philippe	OKBA Saida	VERHULST Sabine	de BERNARD de FAUCONVAL Isabelle	MOLINGHEN Claire	SUPPLÉANTS	DUPIRE David	STEELANDT Thierry	VOUILLEMIN Lucienne	DELCHAMBRE Eric
FELIX-DE GENDT Simone	WILLEM Franc	DOGRU Mahmut	GUSTOT Philippe	CALET Pol	LEFEBVRE Michelle	DEPRIS Dimitri	LINERS Sandra	YUKSEL Zekiye	LEFEVRE Marie-Ange	DOYEN Fabrice	SPLINGARD Karine
LALIEUX Jean-Jacques	COURTOIS Jeanine	HASQUIN Ghislaine	SIMONIS Anne	DI DONATO Maria	CARDINAELLE Martine	BERNIER Nelly	DISLAIRE Michel	ROECK Robert	FRERE Frédéric	DARON Marie-Paule	JOURNIAUX Alain
CORRIAT Emmanuel	PIRET Ludger	ALLART Jean-Marie	VLAMINCK Monique	MINSART Fabrice	de MOREAU d'ANDOY Guillaume	ROLAND Bernard	ADAM Ghislaine	DI RAIMO Michel	RONCHETTE Daniel	LIBERT Ludovic	MOLLE Angélique
SUPPLÉANTS	**SUPPLÉANTS**	**SUPPLÉANTS**	**SUPPLÉANTS**	**SUPPLÉANTS**	**SUPPLÉANTS**	**SUPPLÉANTS**	KUBICZEK Hubert	**SUPPLÉANTS**	**SUPPLÉANTS**	**SUPPLÉANTS**	**SUPPLÉANTS**
CHARLIER Philippe	HUYGENS Daniel	SEGHIN Philippe	BOGAERT Luc	FICHEROULLE Paul	DEPRAETERE Etienne	LAMBERMONT Jacqueline		BENCHEKROUN Zora	MEUNIER Stéphanie	BOUFFIOUX Joël	JOURNIAUX Alain
SALVI Véronique	HELIN Erica	SONNET Philippe	COSSE Renée	MARCHAL Roland	MARTENS Marie-Alix	PIRON Jacques		DUFOUR Danièle	FRERE Nathalie	SEVRAIN Bernadette	GONZE Olympe
ROBBEETS Jean-Pierre	HAID Olivier	KABIMBI Adrienne	LOUAUX Jonathan	POLLART Annick	CORBEAU Etienne	ROMAIN Cédric		COURTOIS Paul	RONCHETTE Daniel	VAN DE MOORTELE Daniel	PEMERS Jean-Claude
NICAISE Marie-Chantal	CHAUVIER Annick	CIGNA Aurélie	DORTANT Stéphanie	ROVILLARD Georges	BOUCHAT Elisabeth	VENY Brigitte		BERRAKI Mansoura	BUFFIN Catherine	DE BOEVERE Maurice	DORVAL Eric
DEHAVAY Philippe	QUERTINMONT Jules	SAMPAOESE Yolande	CORNET Philippe	FLORIDOUZ Marielle	de MOREAU d'ANDOY Guillaume	VASSART Marie-Claire		ROMAIN Roger	LEFEVRE Marie-Ange	SERMEUS Marie-France	ALLARD Angélique
THONON-LALIEUX Liliane	BLANCHARD Marie-Rose	EVRARD Laurence	LEFIN Jacqueline	CAREME Marie-Odette	CARDINAELLE Martine	MONOYER Ginette		PICART Josiane	ELAERTS Patricia	BRUCKMANN Annie	DEL FORGE Isabelle
STILMANT Monique	PIERONT Robert	MEZZORECCHIA Sabine	GERMY Pascal	NIKOLAJEV Nathalie	DUMONT de CHASSART Frédéric	SANTINELLI Adélaïde		MATHOT Michel	RICCI Jean Claude	CECILOT Benoît	VILAIN Henri
DEGROOTE Johanna	COURTOIS Jeanine	LENOIR Perrine	LEONARD Marie-Rose	MENSIER Isabelle	LEFEBVRE Michelle	DRIAUX Serge		CHARLES Georgette	STEELANDT Thierry	HAUTRIVE Henriette	MOLLE Angélique
VISEUR Jean-Jacques	BRYS Geneviève	CHASTEL Olivier	NOLLET Jean-Marc	BOUSMAN Sébastien	DEPRAETERE Jean-Pierre	DUBRAY Jean-Marc		TANASIE Benoît	VERCRUYSSEN Thierry	TASSIN Andrée	AGOZZINO Sabrina

Sicilian Attack

2	Olivier
10	Nicolas
9	Ségolène
8	François
11	José
1	Dominique
3	Marie-George
4	Arlette
12	Frédéric
5	Pat Hibulaire
6	Al Cap
7	Aldo

With 12 candidates, there are more than 479 millions possible combinations!

Integer factorization

100 895 598 169 = 898 423 × 112 303

Number of digits	Time with 100 million of PC
200	5,6 days
300	228 years
450	17 million of years
600	610 000 million of years