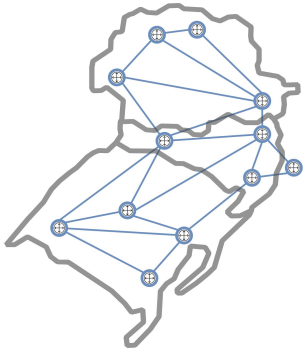
Universidade Federal do Pampa

ERRC 2020 ONLINE



Introdução à Verificação Automática de Protocolos de Segurança com Scyther

Diego Kreutz (UNIPAMPA), Rodrigo Mansilha (UNIPAMPA)
Silvio E. Quincozes (UFF), Tadeu Jenuário (UNIPAMPA)
João Otávio Chervinski (Monash University)

Quem somos?

debian:~$ whoami
Diego Kreutz

- Professor@**UNIPAMPA**
- Coordenador@**UniHacker.Club**
- Interesses:
  - Segurança
  - Redes
  - Sistemas Distribuídos

PPGES
Programa de Pós-Graduação em Engenharia de Software

UNIHACKER.CLUB
PROGRAMA UNIVERSIDADE HACKER

LEA
Laboratório de Estudos Avançados em Computação

Quem somos?

debian:~$ whoami
Rodrigo Mansilha

- Professor@**UNIPAMPA**
- Interesses:
  - Segurança
  - Redes
  - Sistemas Distribuídos

https://sites.unipampa.edu.br/rodrigomansilha/

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PPGES
Programa de Pós-Graduação em Engenharia de Software

LEA
Laboratório de Estudos Avançados em Computação

Quem somos?

- Doutorando@**UFF**
- Interesses:
  - Segurança
  - Redes
  - Internet das Coisas (IoT)

```
debian:~$ whoami
Silvio Quincozes
```

Quem somos?

- Graduando@**UNIPAMPA**
  - Engenharia de Software
- Interesses:
  - Segurança
  - Desenvolvimento de Software

Engenharia de Software

debian:~$ whoami
Tadeu Jenuário

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Quem somos?

debian:~$ whoami
João Chervinski

- Doutorando@**Monash**
- Membro@**UniHacker.Club**
- Interesses:
  - Segurança
  - Blockchains
  - Criptomoedas

MONASH University

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Nível do minicurso

Intermediário

Conteúdo do minicurso

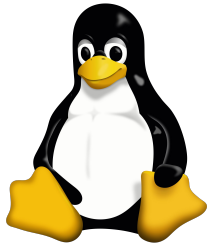
https://s4a.in/github

Conhecimentos desejados

~ — errc2020@d: ~/scyther-linux-v1.1.3 — ssh scyther

```
errc2020@d:~/scyther-linux-v1.1.3$ ls
batcher.sh                          ns3.spdl
Changelog.txt                       nsl3-broken.spdl
combos-book.sh                      nsl3.spdl
combos-ike.sh                       precompute-ike.sh
combos-ikev0.sh                     progressbarDummy.py
combos-ikev1.sh                     Protocols
combos-ikev2.sh                     README.md
combos-iso.sh                       Scripts
generate-attack-graphs.py           Scyther
GNU-General-Public-License.txt      scyther-gui.py
Gui                                 scyther-gui.rc
Images                              scyther-manual.pdf
INSTALL.md                          scyther.py
INSTALL.txt                         test-delta.py
json-scyther.py                     test-mpa.py
make-bsub.py                        Time
mpa.spdl                            todo.txt
notes-brutus-mpa.txt                wiper.sh
errc2020@d:~/scyther-linux-v1.1.3$
```

Linux e terminal / linha de comando



Conhecimentos desejados

```
#!/usr/bin/env python
import pika
import sys

connection = pika.BlockingConnection(
    pika.ConnectionParameters(host='logs.unihacker.club'))
channel = connection.channel()

channel.exchange_declare(exchange='logs', exchange_type='fanout')

message = ' '.join(sys.argv[1:]) or "Info: Coletando Dados!"

channel.basic_publish(exchange='logs', routing_key='', body=message)

print(" Dados enviados %r" % message)

connection.close()
```

Lógica de programação e codificação

Conhecimentos desejados

Noções de

Redes de

Computadores

Conhecimentos desejados

Princípios e Primitivas de Segurança da Informação

Roteiro

- **Introdução**
- A ferramenta Scyther
- O protocolo ACS
- O protocolo WMF
- O protocolo NS
- O protocolo GNSL
- Considerações finais

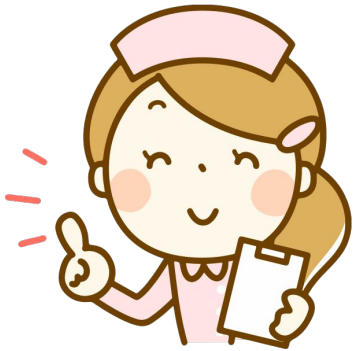
Introdução

LGPD

(**L**ei **G**eral de **P**roteção de **D**ados)

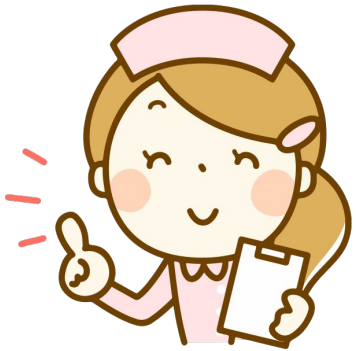
LEI Nº 13.709, DE 14 DE AGOSTO DE 2018.

LGPD: Proteção de Dados



- em armazenamento
- em processamento
- em **trânsito**

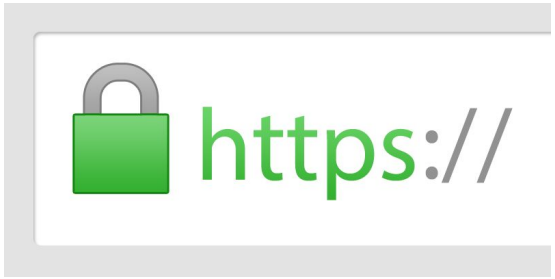
Protocolos de Segurança



- Transfer Layer Security (TLS)
- Secure Shell (SSH)
- Internet Security Protocol (IPSec)
- Diffie-Hellman (DH)
- Internet Key Exchange (IKE)

HTTPS = Segurança?

HTTP + TLS =



HTTPS

https://s4a.in/httpsBR

HTTPS = Segurança?

https://s4a.in/httpsBR

Versão	5k+ sites
SSLv2	2%
SSLv3	5%
TLS 1.0	76%
TLS 1.1	80%
TLS 1.2	97%
TLS 1.3	35%

0% dos sites suportam **APENAS TLS 1.3**

Projeto de Protocolos de Segurança

- Especificação
- Verificação
- Implementação
- Verificação de Código

Projeto de Protocolos de Segurança

- **Especificação**
- Verificação
- Implementação
- Verificação de Código

Semântica agnóstica de verificação

Projeto de Protocolos de Segurança

- Especificação
- **Verificação**
- Implementação
- Verificação de Código

Semântica específica da ferramenta

Projeto de Protocolos de Segurança

- Especificação
- Verificação
- **Implementação**
- Verificação de Código

Tradução para linguagem de programação

Projeto de Protocolos de Segurança

- Especificação
- Verificação
- Implementação
- **Verificação de Código**

Adição de semântica de linguagem de verificação

Projeto de Protocolos de Segurança

- ✓ **Especificação**
- ✓ **Verificação**
- ❑ Implementação
- ❑ Verificação de Código

Foco deste minicurso

Especificação: semântica

1. Alice $\rightarrow$ Bob [Alice, E_K(dadosA)]

Especificação: semântica

1. Alice $\rightarrow$ Bob	[Alice, E_K(dadosA)]
2. Bob $\rightarrow$ Alice	[Bob, E_K(dadosB)]

Especificação: semântica

1. Alice $\rightarrow$ Bob	[Alice, E_K(dadosA)]
2. Bob $\rightarrow$ Alice	[Bob, E_K(dadosB)]
3. Bob, Alice	K $\leftarrow$ H(K $\|\|$ dadosA $\|\|$ dadosB)

Especificação: semântica

1. Alice $\rightarrow$ Bob [Alice, E_{Ke}(dadosA)], $HMAC_{Kh}$

Curiosidade: PFS, PCS, **PQS**

arXiv: https://s4a.in/chavesKeKh

ACM ToPS: https://s4a.in/dVRmID

Chaves distintas para cifra e HMAC

Especificação: semântica

1. Alice $\rightarrow$ Bob	[Alice, E_{Ke}(dadosA)], $HMAC_{Kh}$
2. Bob $\rightarrow$ Alice	[Bob, E_{Ke}(dadosB)], $HMAC_{Kh}$

Especificação: semântica

1. Alice $\rightarrow$ Bob	[Alice, E_{Ke}(dadosA)], $HMAC_{Kh}$
2. Bob $\rightarrow$ Alice	[Bob, E_{Ke}(dadosB)], $HMAC_{Kh}$
3. Bob, Alice	Ke $\leftarrow$ H(Ke $\|\|$ dadosA $\|\|$ dadosB)

Especificação: semântica

1. Alice $\rightarrow$ Bob	[Alice, E_{Ke}(dadosA)], $HMAC_{Kh}$
2. Bob $\rightarrow$ Alice	[Bob, E_{Ke}(dadosB)], $HMAC_{Kh}$
3. Bob, Alice	Ke $\leftarrow$ H(Ke || dadosA || dadosB)
4. Bob, Alice	Kh $\leftarrow$ H(Kh || dadosA || dadosB)

Roteiro

- ✓ Introdução
- ❑ **A ferramenta Scyther**
- ❑ O protocolo ACS
- ❑ O protocolo WMF
- ❑ O protocolo NS
- ❑ O protocolo GNSL
- ❑ Considerações finais

A ferramenta Scyther

- Semânticas Operacionais
- Práticas com Scyther

Semânticas Operacionais

- Termos atômicos
- Tipos predefinidos
- Função hash
- Chaves simétricas
- Chaves assimétricas
- Tipos básicos de eventos
- Eventos de afirmação (claim)

Termos atômicos

- **fresh** : valores pseudo-aleatórios
- **var** : armazena dados recebidos
- **const** : constantes locais

Tipos predefinidos

- **Agent** : agenda das comunicações
- **Function** : define um termo como função
- **Nonce** : termos que armazenam valores

Função hash

- finalidade: resumo criptográfico
- declaração: **hashfunction** `H`
- notação: `H(dado)`

Chave simétricas

- finalidade: encriptação simétrica
- notação: `{dados}termo`
- exemplo: `{dados}k(Alice,Bob)`

Chave assimétricas

- finalidade: encriptação assimétrica
- notação: `sk(Alice), pk(Alice)`
- exemplo: `{dados}pk(Alice)`

Tipos básicos de eventos

- **send** : enviar dados
- **recv** : receber dados
- exemplo:

send_1(`Alice,Bob,{dado}pk(Bob)`)

recv_1(`Alice,Bob,{dado}`**`pk(Bob)`**)

Eventos de afirmação (claim)

- **claim** : modelar propriedades de segurança
- exemplos:

claim(`Bob,Secret,dado`)

claim(`Bob,Nisynch`)

Práticas com Scyther

- Sistema Operacional: `Debian Linux`
- Versão da Scyther: `1.1.3`
- Download: https://s4a.in/scyther
- Descompactar:

```
tar xzfv scyther-linux-v1.1.3.tgz
```

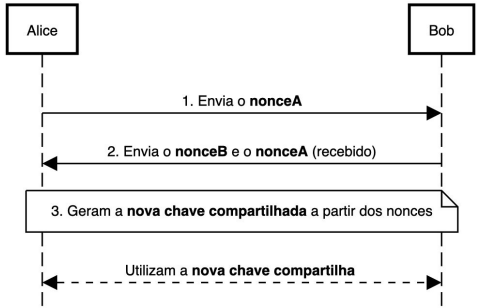
Parâmetros da Scyther

```
-a, --auto-claims

-r, --max-runs=<int>

-A, --all-attacks
```

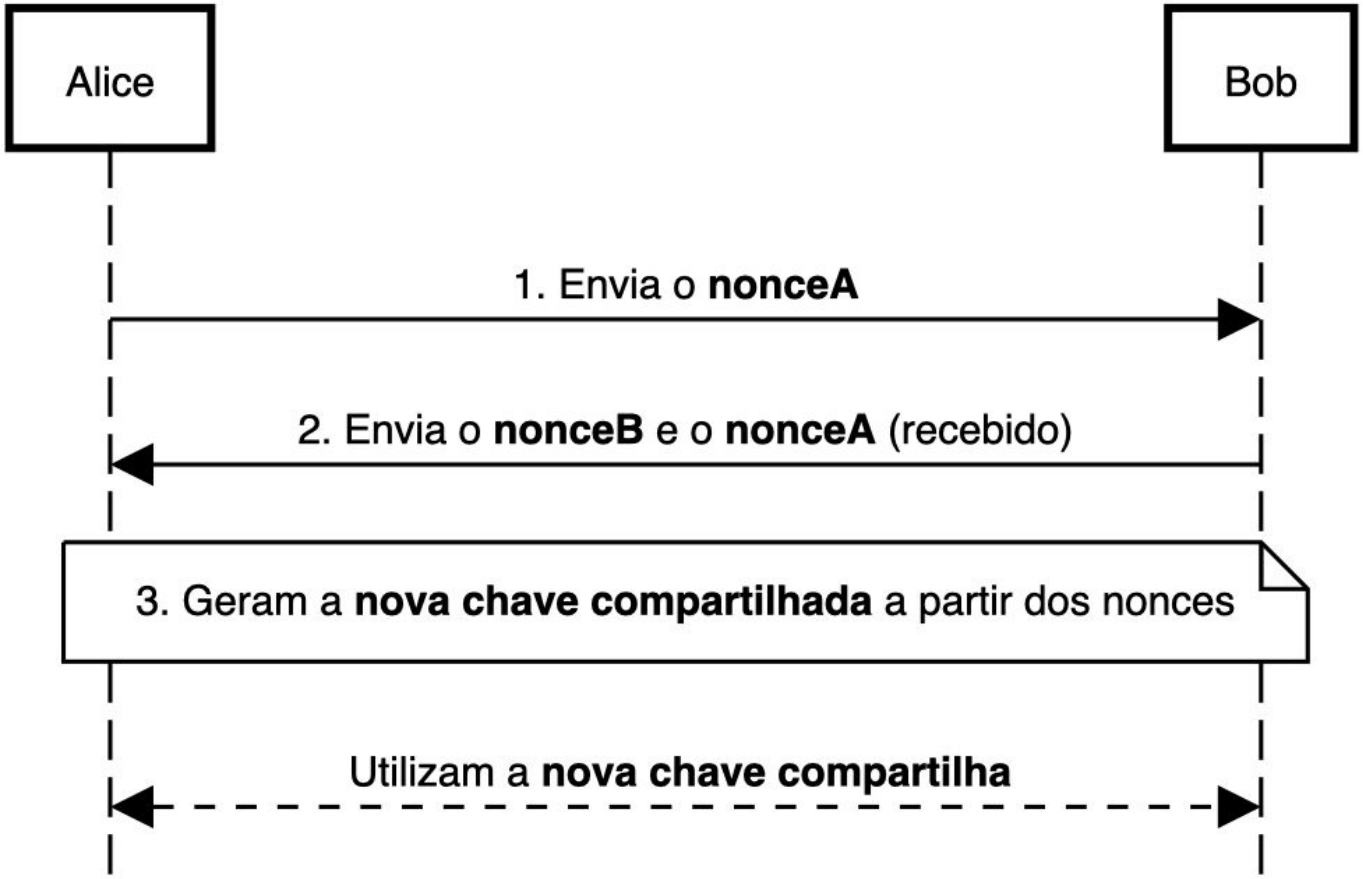
Diagramas: ferramenta



Ferramenta: https://sequencediagram.org

Código dos Diagramas: https://s4a.in/github

Protocolo exemplo (diagrama)



Protocolo exemplo (especificação)

1. Alice $\rightarrow$ Bob $\quad [\text{Alice}, E_{pk_{Bob}}(\text{nonceA})]$

Protocolo exemplo (especificação)

1. Alice $\rightarrow$ Bob	[Alice, $E_{pk_{Bob}}$(nonceA)]
2. Bob $\rightarrow$ Alice	[Bob, $E_{pk_{Alice}}$(nonceB,nonceA)]

Protocolo exemplo (especificação)

1. Alice $\rightarrow$ Bob	[Alice, $E_{pk_{Bob}}$(nonceA)]
2. Bob $\rightarrow$ Alice	[Bob, $E_{pk_{Alice}}$(nonceB,nonceA)]
3. Bob, Alice	K $\leftarrow$ H(nonceA $\|\|$ nonceB)

Protocolo na semântica Scyther

```
1 const pk: Function;
2 secret sk: Function;
3 inversekeys (pk,sk);
4 const Eve: Agent;
5 untrusted Eve;
6 protocol exemplo(Alice,Bob,Eve){
```

Protocolo na semântica Scyther

```
1 const pk: Function;
2 secret sk: Function;
3 inversekeys (pk,sk);
4 const Eve: Agent;
5 untrusted Eve;
6 protocol exemplo(Alice,Bob,Eve){
```

Protocolo na semântica Scyther

```
7    role Alice{
8        fresh nonceA: Nonce;
9        var nonceB: Nonce;
10       send_1(Alice,Bob,{nonceA}pk(Bob));
11       recv_2(Bob,Alice,{nonceA,nonceB}pk(Alice));
12       claim(Alice,Secret,nonceA);
13       claim(Alice,Secret,nonceB);
14       claim(Alice,Nisynch);
15   }
```

Protocolo na semântica Scyther

```
7     role Alice{
8         fresh nonceA: Nonce;
9         var nonceB: Nonce;
10        send_1(Alice,Bob,{nonceA}pk(Bob));
11        recv_2(Bob,Alice,{nonceA,nonceB}pk(Alice));
12        claim(Alice,Secret,nonceA);
13        claim(Alice,Secret,nonceB);
14        claim(Alice,Nisynch);
15    }
```

Protocolo na semântica Scyther

```
7     role Alice{
8         fresh nonceA: Nonce;
9         var nonceB: Nonce;
10        send_1(Alice,Bob,{nonceA}pk(Bob));
11        recv_2(Bob,Alice,{nonceA,nonceB}pk(Alice));
12        claim(Alice,Secret,nonceA);
13        claim(Alice,Secret,nonceB);
14        claim(Alice,Nisynch);
15    }
```

Protocolo na semântica Scyther

```
16      role Bob{
17          var nonceA: Nonce;
18          fresh nonceB: Nonce;
19          recv_1(Alice,Bob,{nonceA}pk(Bob));
20          send_2(Bob,Alice,{nonceA,nonceB}pk(Alice));
21          claim(Bob,Secret,nonceA);
22          claim(Bob,Secret,nonceB);
23          claim(Bob,Nisynch);
24      }
25  }
```

Protocolo na semântica Scyther

```
16      role Bob{
17          var nonceA: Nonce;
18          fresh nonceB: Nonce;
19          recv_1(Alice,Bob,{nonceA}pk(Bob));
20          send_2(Bob,Alice,{nonceA,nonceB}pk(Alice));
21          claim(Bob,Secret,nonceA);
22          claim(Bob,Secret,nonceB);
23          claim(Bob,Nisynch);
24      }
25  }
```

Protocolo na semântica Scyther

```
16      role Bob{
17          var nonceA: Nonce;
18          fresh nonceB: Nonce;
19          recv_1(Alice,Bob,{nonceA}pk(Bob));
20          send_2(Bob,Alice,{nonceA,nonceB}pk(Alice));
21          claim(Bob,Secret,nonceA);
22          claim(Bob,Secret,nonceB);
23          claim(Bob,Nisynch);
24      }
25  }
```

Verificação com a Scyther

Protocolos na semântica Scyther:

https://s4a.in/github

```
d:~$ cd ~/
d:~$ git clone
https://github.com/scyther-lea/errc2020.git
```

Verificação com a Scyther

https://s4a.in/scytherSite

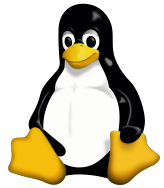
```
d:~$ cd ~/
d:~$ wget
https://people.cispa.io/cas.cremers/downloads/scy
ther/scyther-linux-v1.1.3.tgz
d:~$ tar xzvf scyther-linux-v1.1.3.tgz
d:~$ cd scyther-linux-v1.1.3
d:~$ cp ../errc2020/scyther/*.spdl .
```

Verificação com a Scyther

```
d:~$ ./scyther.py --all-attacks --max-runs=5
protocolo_exemplo.spdl
```

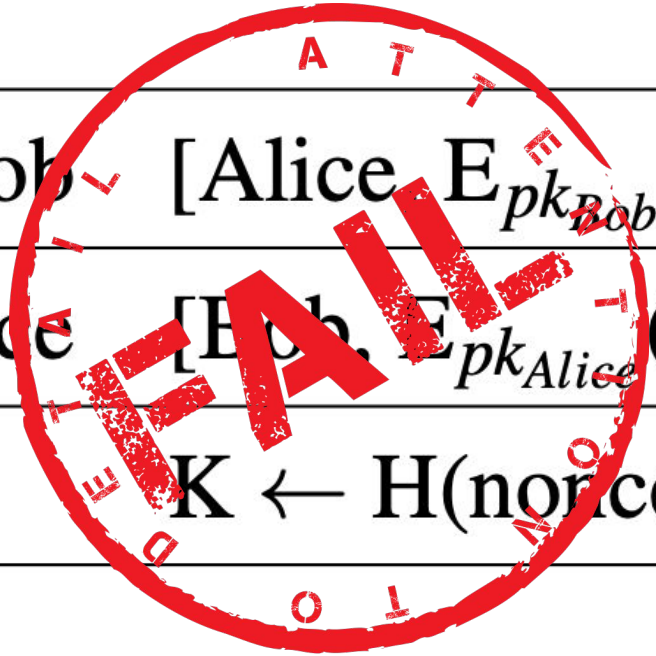
```
./scyther.py --all-attacks --max-runs=5 protocolo_exemplo.spdl

Verification results:
claim id [exemplo,Alice1], Secret(nA) : No attacks.
claim id [exemplo,Alice2], Secret(nB) : No attacks.
claim id [exemplo,Alice3], Nisynch    : No attacks.
claim id [exemplo,Bob1], Secret(nA)   : Exactly 1 attack.
claim id [exemplo,Bob2], Secret(nB)   : No attacks.
claim id [exemplo,Bob3], Nisynch      : Exactly 1 attack.
```



Protocolo exemplo (vulnerável)

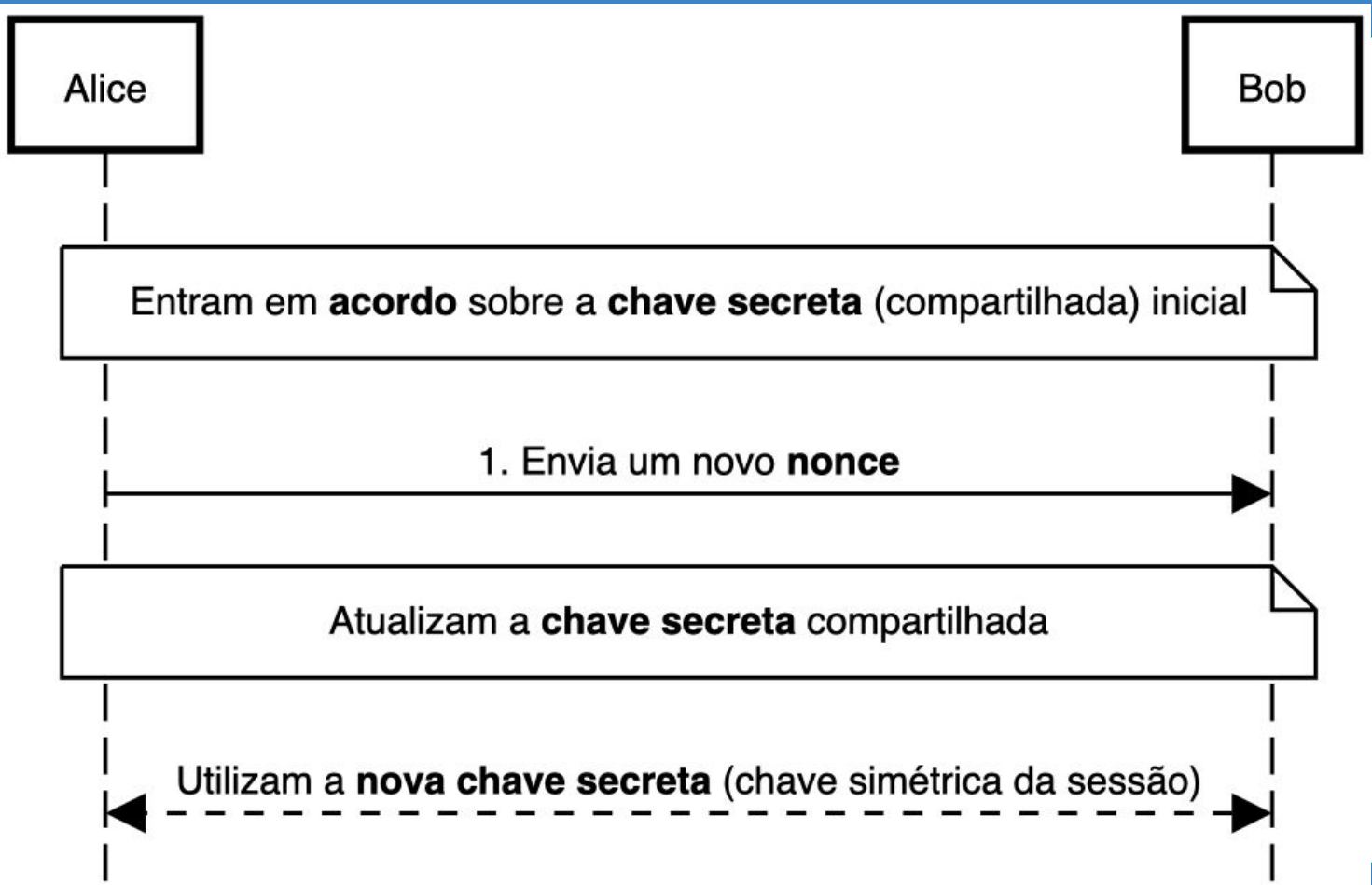
1. Alice → Bob [Alice, $E_{pk_{Bob}}$(nonceA)]
2. Bob → Alice [Bob, $E_{pk_{Alice}}$(nonceB,nonceA)]
3. Bob, Alice $K \leftarrow H(nonceA \,||\, nonceB)$



Roteiro

- ✓ Introdução
- ✓ A ferramenta Scyther
- ❑ **O protocolo ACS**
- ❑ O protocolo WMF
- ❑ O protocolo NS
- ❑ O protocolo GNSL
- ❑ Considerações finais

O protocolo ACS (diagrama)



O protocolo ACS (especificação)

1. Alice $\rightarrow$ Bob $\quad [E_K(\text{nonce})]$

O protocolo ACS (especificação)

1. Alice $\rightarrow$ Bob	$[E_K(\text{nonce})]$
2. Bob, Alice	$K \leftarrow H(K \,\|\| \text{nonce})$

O protocolo ACS (adicionar HMAC)

1. Alice $\rightarrow$ Bob	$[E_K(\text{nonce})]$, HMAC
2. Bob, Alice	$K \leftarrow H(K \,\|\|\, \text{nonce})$

Exemplo: https://s4a.in/auth4app

O protocolo ACS (semântica Scyther)

```
1  secret K: SessionKey;
2  const Eve: Agent;
3  untrusted Eve;
4  protocol ACS(Alice,Bob,Eve){
```

Há uma chave “k” (minúscula) padrão na Scyther

O protocolo ACS (semântica Scyther)

```
1  secret K: SessionKey;
2  const Eve: Agent;
3  untrusted Eve;
4  protocol ACS(Alice,Bob,Eve){
```

O protocolo ACS (semântica Scyther)

```
1 secret K: SessionKey;
2 const Eve: Agent;
3 untrusted Eve;
4 protocol ACS(Alice,Bob,Eve){
```

O protocolo ACS (semântica Scyther)

```
5    role Alice{
6        fresh nonce: Nonce;
7        send_1(Alice,Bob,{nonce}K(Alice,Bob));
8        claim_ Alice1(Alice,Secret,nonce);
9        claim_ Alice2(Alice,Secret,K);
10   }
11   role Bob{
12       var nonce: Nonce;
13       recv_1(Alice,Bob,{nonce}K(Alice,Bob));
14       claim_Bob1(Bob,Secret,nonce);
15       claim_Bob2(Bob,Secret,K);
16   }
```

O protocolo ACS (semântica Scyther)

```
5    role Alice{
6        fresh nonce: Nonce;
7        send_1(Alice,Bob,{nonce}K(Alice,Bob));
8        claim_ Alice1(Alice,Secret,nonce);
9        claim_ Alice2(Alice,Secret,K);
10   }
11   role Bob{
12       var nonce: Nonce;
13       recv_1(Alice,Bob,{nonce}K(Alice,Bob));
14       claim_Bob1(Bob,Secret,nonce);
15       claim_Bob2(Bob,Secret,K);
16   }
```

O protocolo ACS (semântica Scyther)

```
5    role Alice{
6        fresh nonce: Nonce;
7        send_1(Alice,Bob,{nonce}K(Alice,Bob));
8        claim_ Alice1(Alice,Secret,nonce);
9        claim_ Alice2(Alice,Secret,K);
10   }
11   role Bob{
12       var nonce: Nonce;
13       recv_1(Alice,Bob,{nonce}K(Alice,Bob));
14       claim_Bob1(Bob,Secret,nonce);
15       claim_Bob2(Bob,Secret,K);
16   }
```

O protocolo ACS (semântica Scyther)

```
5    role Alice{
6        fresh nonce: Nonce;
7        send_1(Alice,Bob,{nonce}K(Alice,Bob));
8        claim_ Alice1(Alice,Secret,nonce);
9        claim_ Alice2(Alice,Secret,K);
10   }
11   role Bob{
12       var nonce: Nonce;
13       recv_1(Alice,Bob,{nonce}K(Alice,Bob));
14       claim_Bob1(Bob,Secret,nonce);
15       claim_Bob2(Bob,Secret,K);
16   }
```

O protocolo ACS (semântica Scyther)

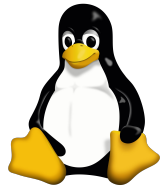
```
1  secret K: SessionKey;
2  const Eve: Agent;
3  untrusted Eve;
4  protocol ACS(Alice,Bob,Eve){
5     role Alice{
6        fresh nonce: Nonce;
7        send_1(Alice,Bob,{nonce}K(Alice,Bob));
8        claim_ Alice1(Alice,Secret,nonce);
9        claim_ Alice2(Alice,Secret,K);
10    }
11    role Bob{
12       var nonce: Nonce;
13       recv_1(Alice,Bob,{nonce}K(Alice,Bob));
14       claim_Bob1(Bob,Secret,nonce);
15       claim_Bob2(Bob,Secret,K);
16    }
17 }
```

O protocolo ACS (verificação Scyther)

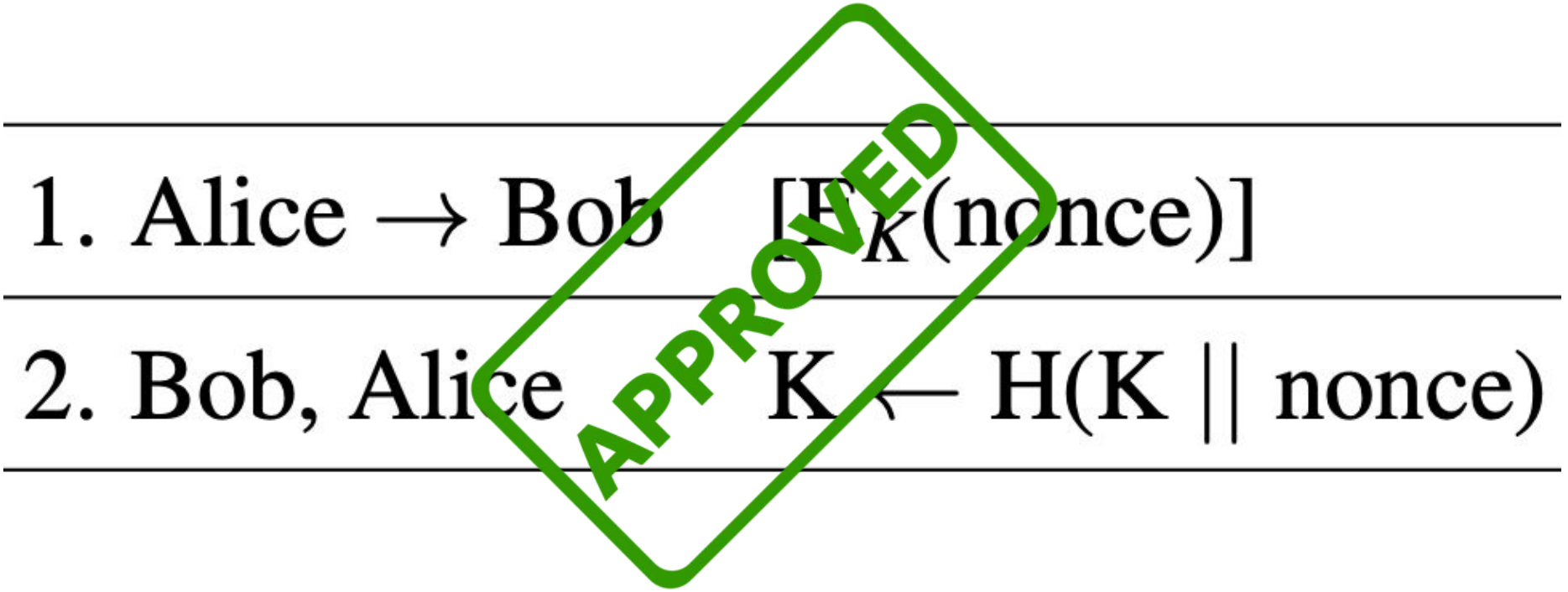
```
d:~$ ./scyther.py --all-attacks --max-runs=5
protocolo_acs.spdl
```

```
./scyther.py  --all-attacks  --max-runs=5 protocolo_acs.spdl

Verification results:
claim id [ACS,Alice1], Secret(nonce)  : No attacks.
claim id [ACS,Alice2], Secret(K)      : No attacks.
claim id [ACS,Bob1], Secret(nonce)    : No attacks.
claim id [ACS,Bob2], Secret(K)        : No attacks.
```



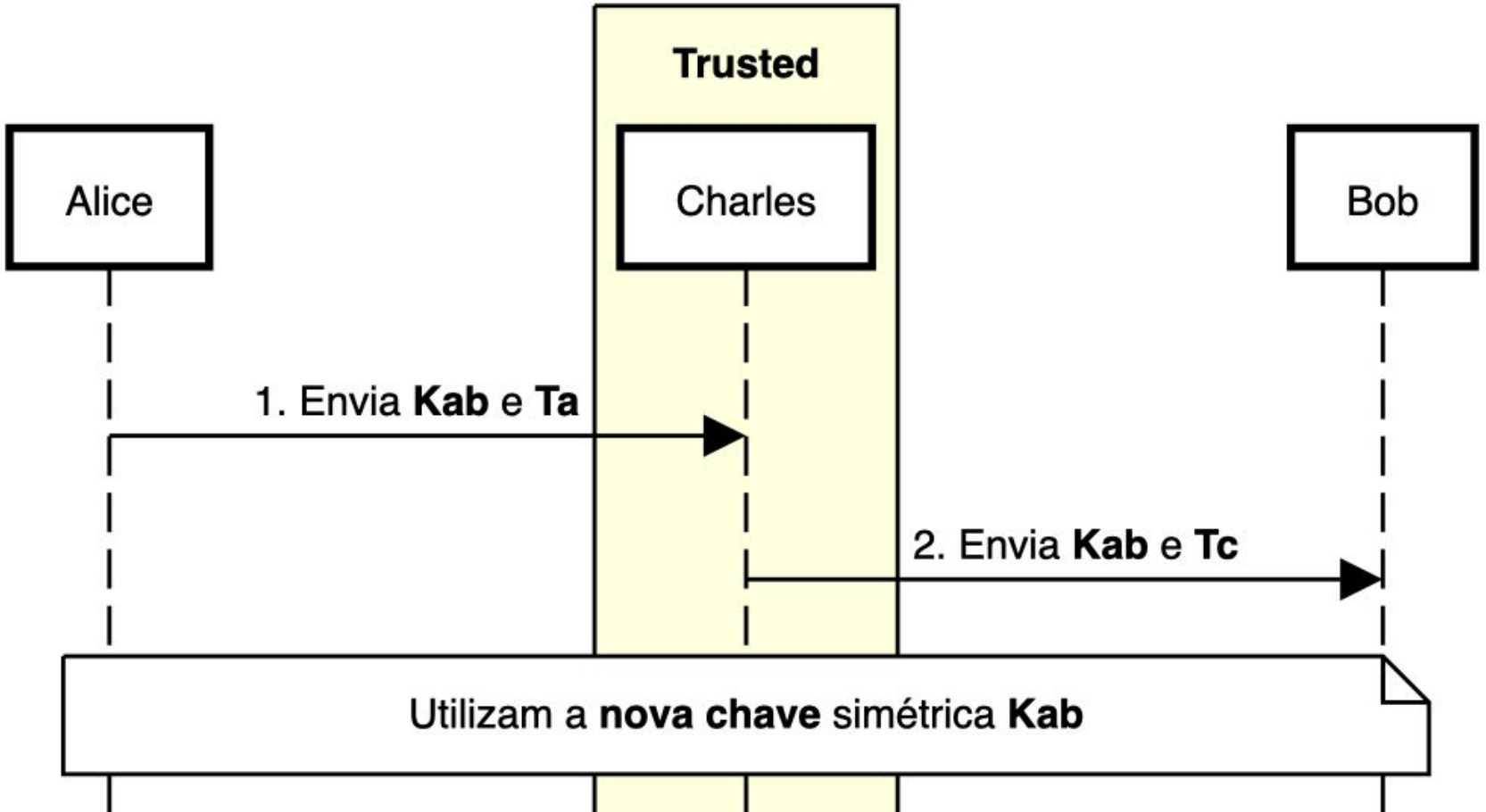
O protocolo ACS (aprovado pela Scyther)



Roteiro

- ✓ Introdução
- ✓ A ferramenta Scyther
- ✓ O protocolo ACS
- ❑ **O protocolo WMF**
- ❑ O protocolo NS
- ❑ O protocolo GNSL
- ❑ Considerações finais

O protocolo WMF (diagrama)



O protocolo WMF (especificação)

1. Alice $\rightarrow$ Charles $\quad [\text{Alice}, E_{K_{ac}}(T_a, \text{Bob}, K_{ab})]$

O protocolo WMF (especificação)

1. Alice $\rightarrow$ Charles	[Alice, $E_{K_{ac}}(T_a, Bob, K_{ab})$]
2. Charles $\rightarrow$ Bob	[$E_{K_{bc}}(T_c, Alice, K_{ab})$]

O protocolo WMF (semântica Scyther)

```
5    role Alice{
6        fresh Kab: SessionKey;
7        fresh Ta: TimeStamp;
8        send_1(Alice,Charles,Alice,{Alice,Ta,Bob,Kab}k(Alice,Charles));
9        claim_ Alice1(Alice,Secret,Kab);
10       claim_ Alice2(Alice,Empty,(Fresh,Kab));
11   }
```

O protocolo WMF (semântica Scyther)

```
5    role Alice{
6        fresh Kab: SessionKey;
7        fresh Ta: TimeStamp;
8        send_1(Alice,Charles,Alice,{Alice,Ta,Bob,Kab}k(Alice,Charles));
9        claim_ Alice1(Alice,Secret,Kab);
10       claim_ Alice2(Alice,Empty,(Fresh,Kab));
11   }
```

O protocolo WMF (semântica Scyther)

```
5    role Alice{
6        fresh Kab: SessionKey;
7        fresh Ta: TimeStamp;
8        send_1(Alice,Charles,Alice,{Alice,Ta,Bob,Kab}k(Alice,Charles));
9        claim_ Alice1(Alice,Secret,Kab);
10       claim_ Alice2(Alice,Empty,(Fresh,Kab));
11   }
```

O protocolo WMF (semântica Scyther)

```
12    role Bob{
13        var Tc: TimeStamp;
14        var Kab: SessionKey;
15        recv_2(Charles,Bob,{Charles,Tc,Alice,Kab}k(Bob,Charles));
16        claim_Bob1(Bob,Secret,Kab);
17        claim_Bob2(Bob,Nisynch);
18        claim_Bob3(Bob,Empty,(Fresh,Kab));
19    }
```

O protocolo WMF (semântica Scyther)

```
12    role Bob{
13        var Tc: TimeStamp;
14        var Kab: SessionKey;
15        recv_2(Charles,Bob,{Charles,Tc,Alice,Kab}k(Bob,Charles));
16        claim_Bob1(Bob,Secret,Kab);
17        claim_Bob2(Bob,Nisynch);
18        claim_Bob3(Bob,Empty,(Fresh,Kab));
19    }
```

O protocolo WMF (semântica Scyther)

```
12    role Bob{
13        var Tc: TimeStamp;
14        var Kab: SessionKey;
15        recv_2(Charles,Bob,{Charles,Tc,Alice,Kab}k(Bob,Charles));
16        claim_Bob1(Bob,Secret,Kab);
17        claim_Bob2(Bob,Nisynch);
18        claim_Bob3(Bob,Empty,(Fresh,Kab));
19    }
```

O protocolo WMF (semântica Scyther)

```
20    role Charles{
21        var Kab: SessionKey;
22        var Ta: TimeStamp;
23        fresh Tc:TimeStamp;
24        recv_1( Alice,Charles,Alice,{Alice,Ta,Bob,Kab}k(Alice,Charles));
25        send_2(Charles,Bob,{Charles,Tc,Alice,Kab}k(Bob,Charles));
26    }
```

O protocolo WMF (semântica Scyther)

```
20    role Charles{
21        var Kab: SessionKey;
22        var Ta: TimeStamp;
23        fresh Tc:TimeStamp;
24        recv_1( Alice,Charles,Alice,{Alice,Ta,Bob,Kab}k(Alice,Charles));
25        send_2(Charles,Bob,{Charles,Tc,Alice,Kab}k(Bob,Charles));
26    }
```

O protocolo WMF (semântica Scyther)

```
20    role Charles{
21        var Kab: SessionKey;
22        var Ta: TimeStamp;
23        fresh Tc:TimeStamp;
24        recv_1( Alice,Charles,Alice,{Alice,Ta,Bob,Kab}k(Alice,Charles));
25        send_2(Charles,Bob,{Charles,Tc,Alice,Kab}k(Bob,Charles));
26    }
```

O protocolo WMF (semântica Scyther)

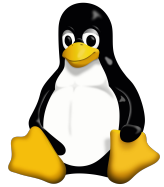
Exemplo WMF em: https://s4a.in/github

```
d:~$ git clone https://github.com/scyther-lea/errc2020.git
d:~$ cd errc2020/scyther
d:~$ vim protocolo_wmf.spdl
```

O protocolo WMF (verificação Scyther)

```
./scyther.py --auto-claims --all-attacks protocolo_wmf.spdl

Verification results:
claim id [WMF,Alice3], Secret(Ta)      : No attacks.
claim id [WMF,Alice4], Secret(Kab)     : No attacks within bounds.
claim id [WMF,Alice5], Alive           : Exactly 1 attack.
claim id [WMF,Alice6], Weakagree       : Exactly 1 attack.
claim id [WMF,Alice7], Niagree         : No attacks.
claim id [WMF,Alice8], Nisynch         : No attacks.
claim id [WMF,Bob4], Secret(Kab)       : No attacks within bounds.
claim id [WMF,Bob5], Secret(Tc)        : No attacks within bounds.
claim id [WMF,Bob6], Alive             : Exactly 1 attack.
claim id [WMF,Bob7], Weakagree         : Exactly 1 attack.
claim id [WMF,Bob8], Niagree           : At least 3 attacks.
claim id [WMF,Bob9], Nisynch           : At least 3 attacks.
claim id [WMF,Charles1], Secret(Tc)    : No attacks within bounds.
claim id [WMF,Charles2], Secret(Ta)    : No attacks within bounds.
claim id [WMF,Charles3], Secret(Kab)   : No attacks within bounds.
claim id [WMF,Charles4], Alive         : Exactly 1 attack.
claim id [WMF,Charles5], Weakagree     : Exactly 1 attack.
claim id [WMF,Charles6], Niagree       : At least 3 attacks.
claim id [WMF,Charles7], Nisynch       : At least 3 attacks.
```



O protocolo WMF (ataques)

1. Alice → Charles [Alice, $E_{K_{ac}}(T_a, \text{Bob}, K_{ab})$]

2. Charles → Bob [$E_{K_{bc}}(T_c, \text{Alice}, K_{ab})$]

O protocolo WMF (pontos fracos)

- Requer um relógio global (*timestamps*)
- Charles possui acesso às chaves
- Chave de sessão Kab definida por Alice
- Ataques de *replay* (intervalo do *timestamp*)
- Protocolo *stateful* (Charles)

O protocolo WMF-Lowe (especificação)

nonce para autenticação mútua

1. Alice → C	e, $E_{K_{ac}}(T_a, Bob, K_{ab})$]
2. Charles →	$_c$(T_c, Alice, K_{ab})]
3. Bob → Alice	[$E_{K_{ab}}$(nonceB)]
4. Alice → Bob	[$E_{K_{ab}}$(nonceB+1)]

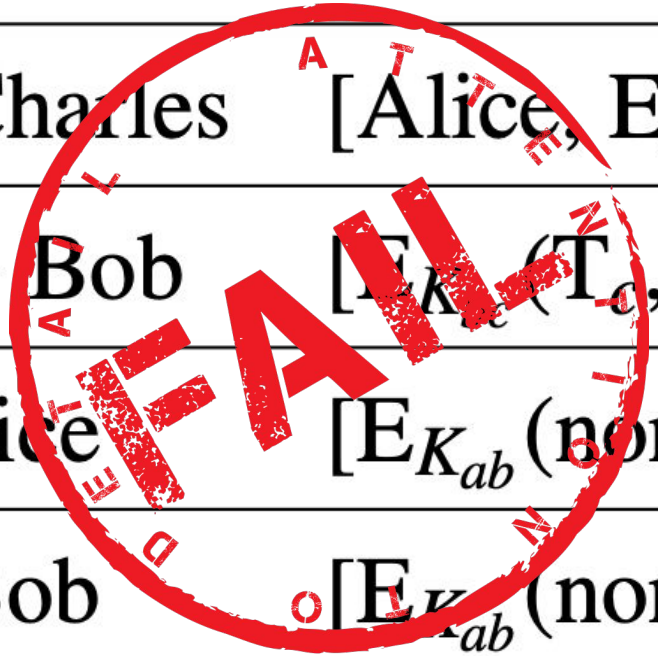
O protocolo WMF-Lowe (verificação)

```
d:~$ ./scyther.py --all-attacks --max-runs=5
protocolo_wmf_lowe.spdl
```

```
errc2020@d:~/scyther-linux-v1.1.3$ ./scyther.py --all-attacks --max-runs=5
protocolo_wmf_lowe.spdl
Verification results:
claim id [WMF-Lowe,Alice1], Secret(Kab) : No attacks within bounds.
claim id [WMF-Lowe,Alice2], Nisynch     : At least 3 attacks.
claim id [WMF-Lowe,Alice4], Secret(nonceB)      : No attacks within bounds.
claim id [WMF-Lowe,Bob1], Secret(Kab)   : No attacks within bounds.
claim id [WMF-Lowe,Bob2], Nisynch       : At least 3 attacks.
claim id [WMF-Lowe,Bob4], Secret(nonceB)        : No attacks within bounds.
```

O protocolo WMF-Lowe (ataques)

1. Alice → Charles	[Alice, $E_{K_{ac}}(T_a,\text{Bob},K_{ab})$]
2. Charles → Bob	[$E_{K_{cb}}(T_c,\text{Alice},K_{ab})$]
3. Bob → Alice	[$E_{K_{ab}}(\text{nonceB})$]
4. Alice → Bob	[$E_{K_{ab}}(\text{nonceB}+1)$]



Roteiro

- ✓ Introdução
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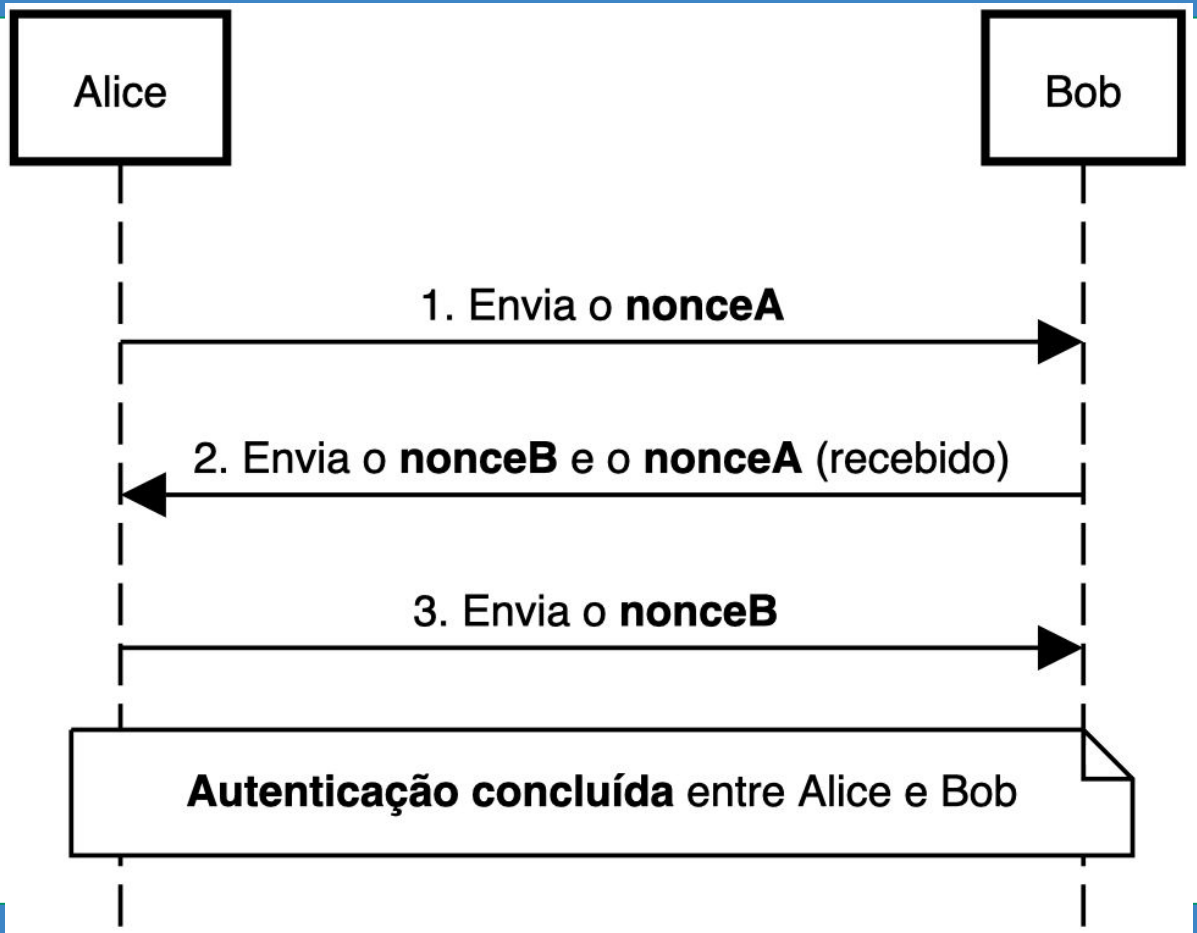
- ✓ O protocolo WMF
- ❑ **O protocolo NS**
- ❑ O protocolo GNSL
- ❑ Considerações finais

O protocolo NS (diagrama)

Autenticação para dois Participantes



O protocolo NS (especificação)

1. Alice $\rightarrow$ Bob $\quad [E_{pk_{Bob}}(\text{Alice}, \text{nonceA})]$

O protocolo NS (especificação)

1. Alice $\rightarrow$ Bob	$[E_{pk_{Bob}}(\text{Alice, nonceA})]$
2. Bob $\rightarrow$ Alice	$[E_{pk_{Alice}}(\text{nonceA, nonceB})]$

O protocolo NS (especificação)

1. Alice $\rightarrow$ Bob	$[E_{pk_{Bob}}(\text{Alice, nonceA})]$
2. Bob $\rightarrow$ Alice	$[E_{pk_{Alice}}(\text{nonceA, nonceB})]$
3. Alice $\rightarrow$ Bob	$[E_{pk_{Bob}}(\text{nonceB})]$

O protocolo NS (semântica Scyther)

```
1 const pk: Function;
2 secret sk: Function;
3 inversekeys (pk,sk);
4 const Eve: Agent;
5 untrusted Eve;
6 protocol NS(Alice,Bob,Eve){
```

O protocolo NS (semântica Scyther)

```
7    role Alice{
8        fresh nonceA: Nonce;
9        var nonceB: Nonce;
10       send_1(Alice,Bob,{Alice,nonceA}pk(Bob));
11       recv_2(Bob,Alice,{nonceA,nonceB}pk(Alice));
12       send_3(Alice,Bob,{nonceB}pk(Bob));
13       claim(Alice,Secret,nonceA);
14       claim(Alice,Secret,nonceB);
15       claim(Alice,Nisynch);
16   }
```

O protocolo NS (semântica Scyther)

```
7     role Alice{
8         fresh nonceA: Nonce;
9         var nonceB: Nonce;
10        send_1(Alice,Bob,{Alice,nonceA}pk(Bob));
11        recv_2(Bob,Alice,{nonceA,nonceB}pk(Alice));
12        send_3(Alice,Bob,{nonceB}pk(Bob));
13        claim(Alice,Secret,nonceA);
14        claim(Alice,Secret,nonceB);
15        claim(Alice,Nisynch);
16    }
```

O protocolo NS (semântica Scyther)

```
7     role Alice{
8         fresh nonceA: Nonce;
9         var nonceB: Nonce;
10        send_1(Alice,Bob,{Alice,nonceA}pk(Bob));
11        recv_2(Bob,Alice,{nonceA,nonceB}pk(Alice));
12        send_3(Alice,Bob,{nonceB}pk(Bob));
13        claim(Alice,Secret,nonceA);
14        claim(Alice,Secret,nonceB);
15        claim(Alice,Nisynch);
16    }
```

O protocolo NS (semântica Scyther)

```
17    role Bob{
18        var nonceA: Nonce;
19        fresh nonceB: Nonce;
20        recv_1(Alice,Bob,{Alice,nonceA}pk(Bob));
21        send_2(Bob,Alice,{nonceA,nonceB}pk(Alice));
22        recv_3(Alice,Bob,{nonceB}pk(Bob));
23        claim(Bob,Secret,nonceA);
24        claim(Bob,Secret,nonceB);
25        claim(Bob,Nisynch);
26    }
```

O protocolo NS (semântica Scyther)

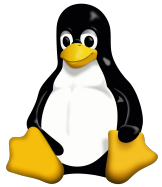
```
17      role Bob{
18          var nonceA: Nonce;
19          fresh nonceB: Nonce;
20          recv_1(Alice,Bob,{Alice,nonceA}pk(Bob));
21          send_2(Bob,Alice,{nonceA,nonceB}pk(Alice));
22          recv_3(Alice,Bob,{nonceB}pk(Bob));
23          claim(Bob,Secret,nonceA);
24          claim(Bob,Secret,nonceB);
25          claim(Bob,Nisynch);
26      }
```

O protocolo NS (semântica Scyther)

```
17      role Bob{
18          var nonceA: Nonce;
19          fresh nonceB: Nonce;
20          recv_1(Alice,Bob,{Alice,nonceA}pk(Bob));
21          send_2(Bob,Alice,{nonceA,nonceB}pk(Alice));
22          recv_3(Alice,Bob,{nonceB}pk(Bob));
23          claim(Bob,Secret,nonceA);
24          claim(Bob,Secret,nonceB);
25          claim(Bob,Nisynch);
26      }
```

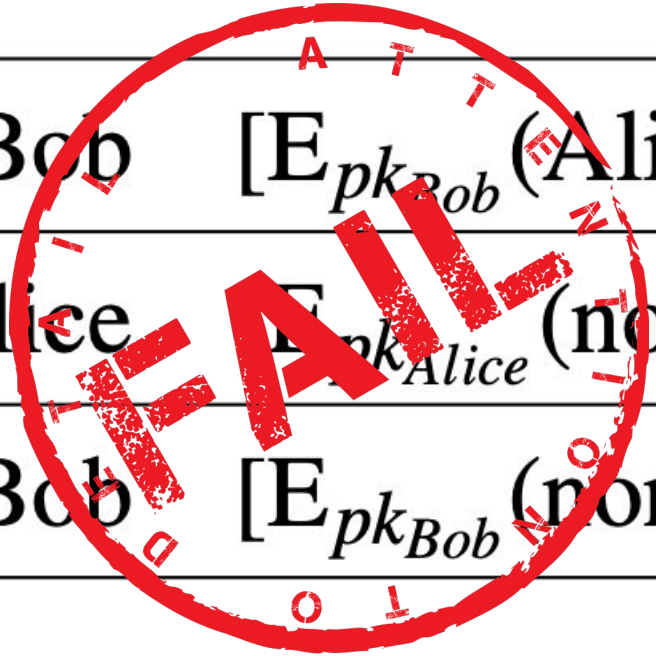
O protocolo NS (verificação Scyther)

```
d:~$ ./scyther.py --all-attacks --max-runs=5
protocolo_ns.spdl

./scyther.py --all-attacks --max-runs=5 protocolo_ns.spdl

Verification results:
claim id [NS,Alice1], Secret(nonceA)   : No attacks.
claim id [NS,Alice2], Secret(nonceB)   : No attacks.
claim id [NS,Alice3], Nisynch          : No attacks.
claim id [NS,Bob1],   Secret(nonceA)   : Exactly 1 attack.
claim id [NS,Bob2],   Secret(nonceB)   : Exactly 1 attack.
claim id [NS,Bob3],   Nisynch          : Exactly 1 attack.
```



O protocolo NS (ataque)

1. Alice → Bob $[E_{pk_{Bob}}(\text{Alice}, \text{nonceA})]$
2. Bob → Alice $[E_{pk_{Alice}}(\text{nonceA}, \text{nonceB})]$
3. Alice → Bob $[E_{pk_{Bob}}(\text{nonceB})]$



O protocolo NS (ataque)

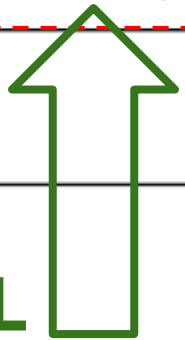
1. Alice $\rightarrow$ Bob $[E_{pk_{Bob}}(\text{Alice, nonceA})]$

2. Bob $\rightarrow$ Alice $[E_{pk_{Alice}}(\text{nonceA, nonceB})]$

3. Alice $\rightarrow$ Bob $[E_{pk_{Bob}}(\text{nonceB})]$

O protocolo NS (correção - NSL)

1. Alice $\rightarrow$ Bob $[E_{pk_{Bob}}(\text{Alice}, \text{nonceA})]$
2. Bob $\rightarrow$ Alice $[E_{pk_{Alice}}(\text{nonceA}, \text{nonceB}, \text{Bob})]$
3. Alice $\rightarrow$ Bob $[E_{pk_{Bob}}(\text{nonceB})]$

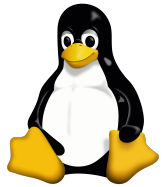


Protocolo NSL

O protocolo NSL (verificação Scyther)

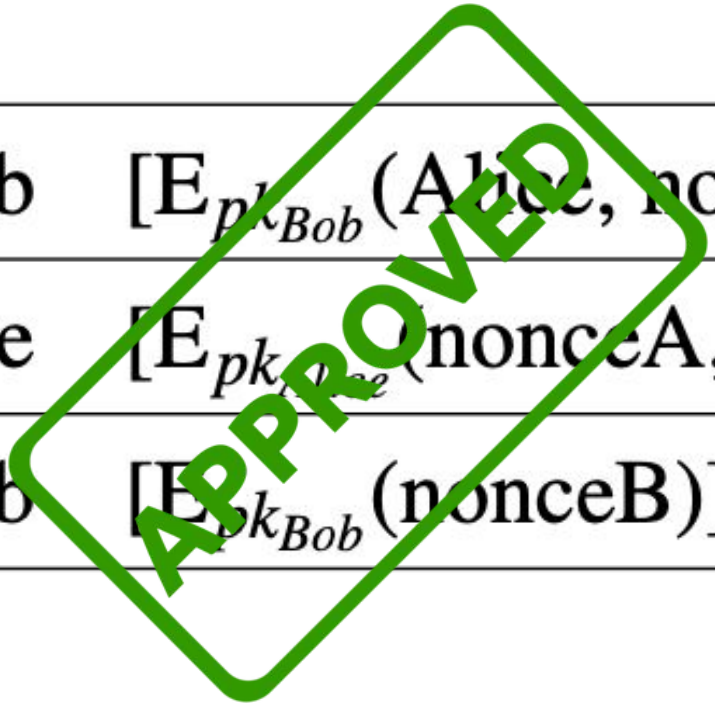
```
debian:~$ ./scyther.py --all-attacks --max-runs=5
protocolo_nsl.spdl
```

```
./scyther.py --all-attacks --max-runs=5 protocolo_ns_corrigido.spdl

Verification results:
claim id [NS,Alice1], Secret(nonceA)   : No attacks.
claim id [NS,Alice2], Secret(nonceB)   : No attacks.
claim id [NS,Alice3], Nisynch          : No attacks.
claim id [NS,Bob1],   Secret(nonceA)   : No attacks.
claim id [NS,Bob2],   Secret(nonceB)   : No attacks.
claim id [NS,Bob3],   Nisynch          : No attacks.
```



O protocolo NSL (especificação)

1. Alice $\rightarrow$ Bob $[E_{pk_{Bob}}(\text{Alice}, \text{nonceA})]$
2. Bob $\rightarrow$ Alice $[E_{pk_{Alice}}(\text{nonceA}, \text{nonceB}, \text{Bob})]$
3. Alice $\rightarrow$ Bob $[E_{pk_{Bob}}(\text{nonceB})]$



Roteiro

- ✓ Introdução
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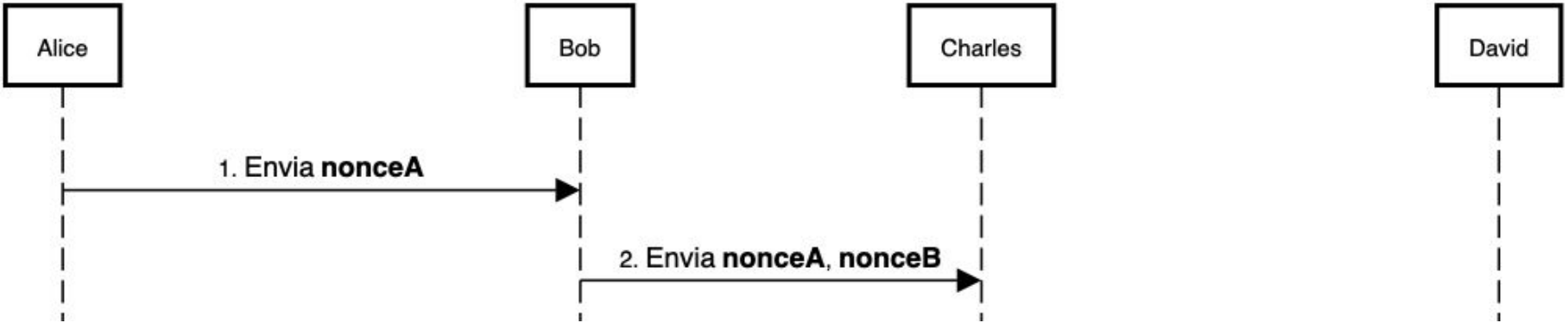
O protocolo GNSL (conceito)

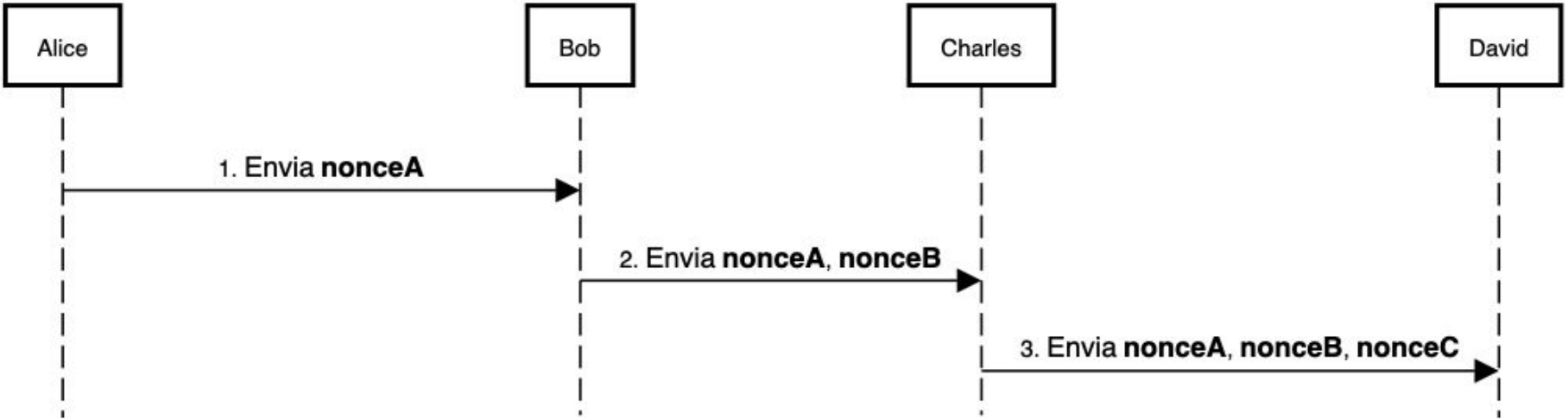
- NSL generalizado para múltiplas entidades
  - Substitui autenticação mútua aos pares
- Cada mensagem carrega informações sobre "todos"
  - Reduz o número de mensagens
  - Pressupõe confiança nas entidades autenticadas

O protocolo 4GNSL (diagrama)

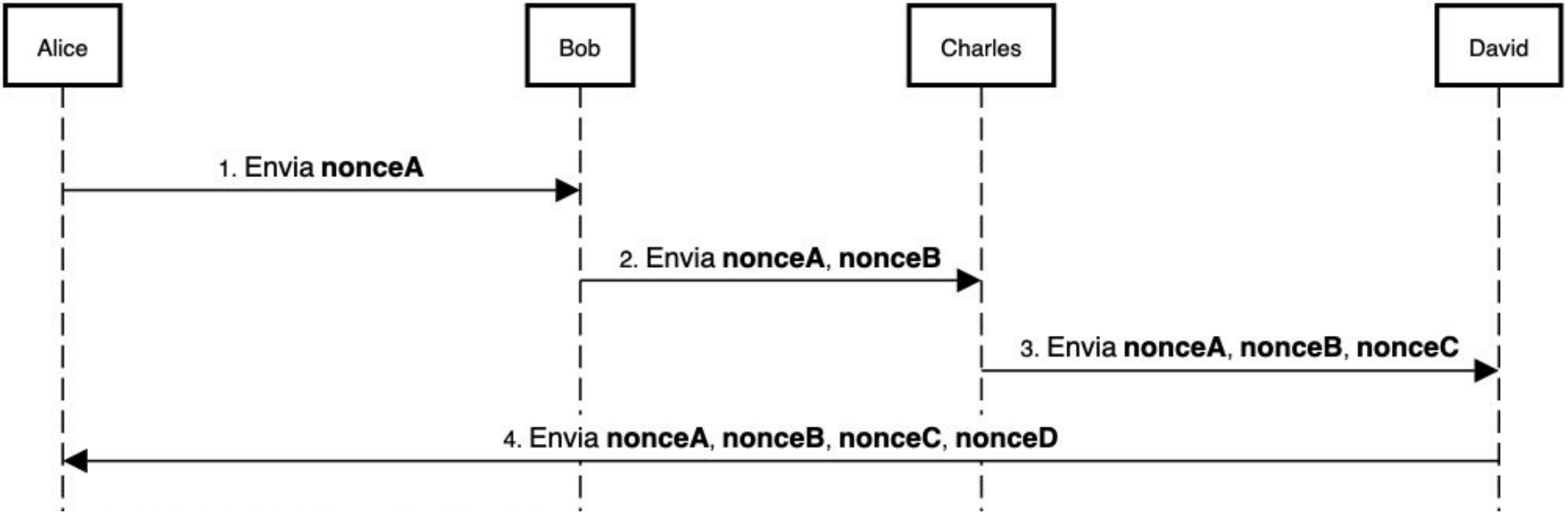
O protocolo 4GNSL (diagrama)



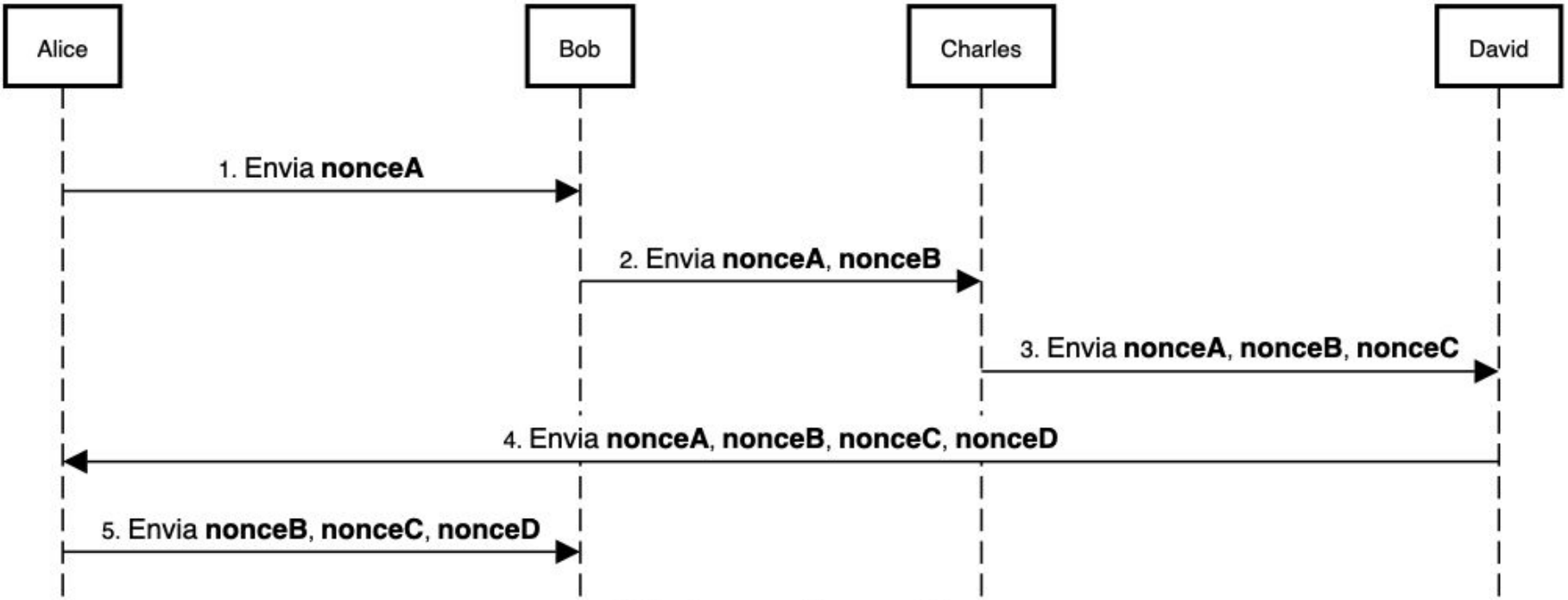
O protocolo 4GNSL (diagrama)



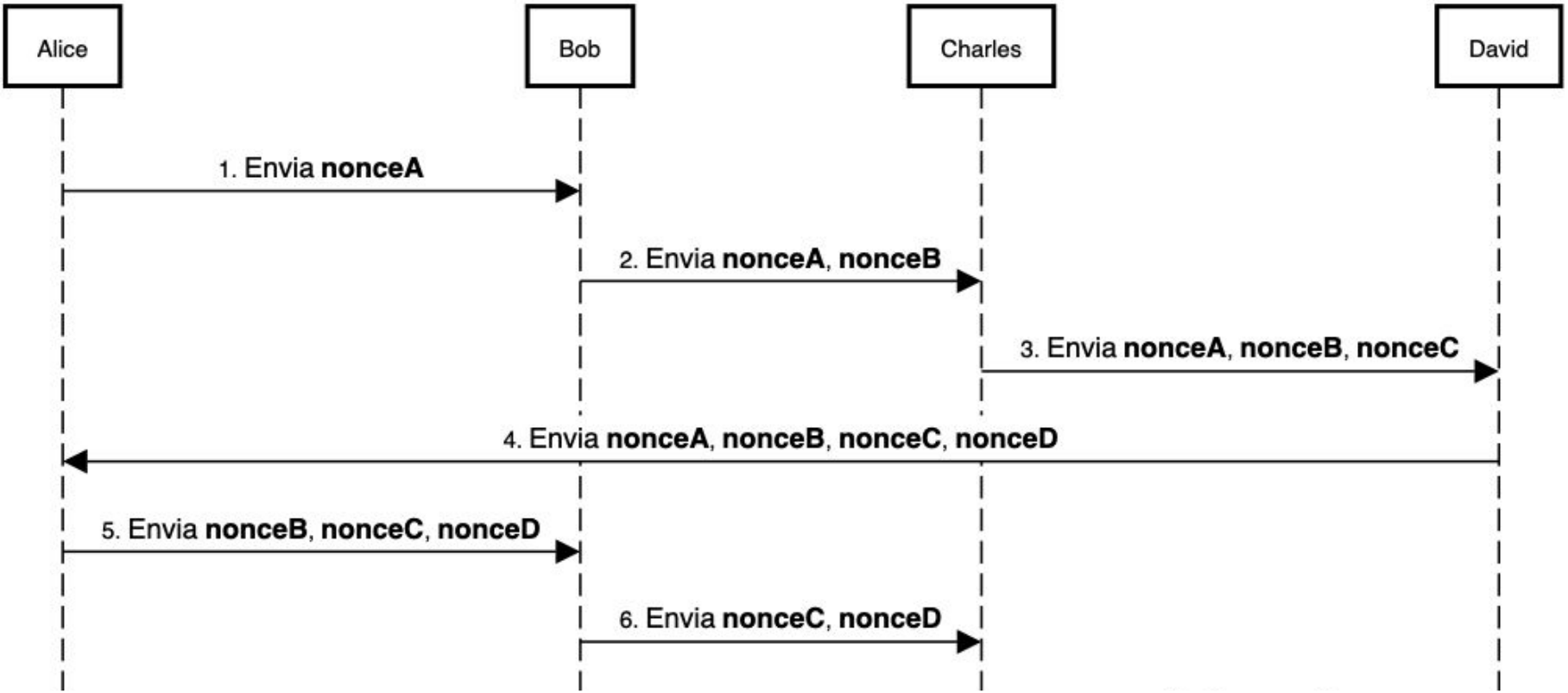
O protocolo 4GNSL (diagrama)



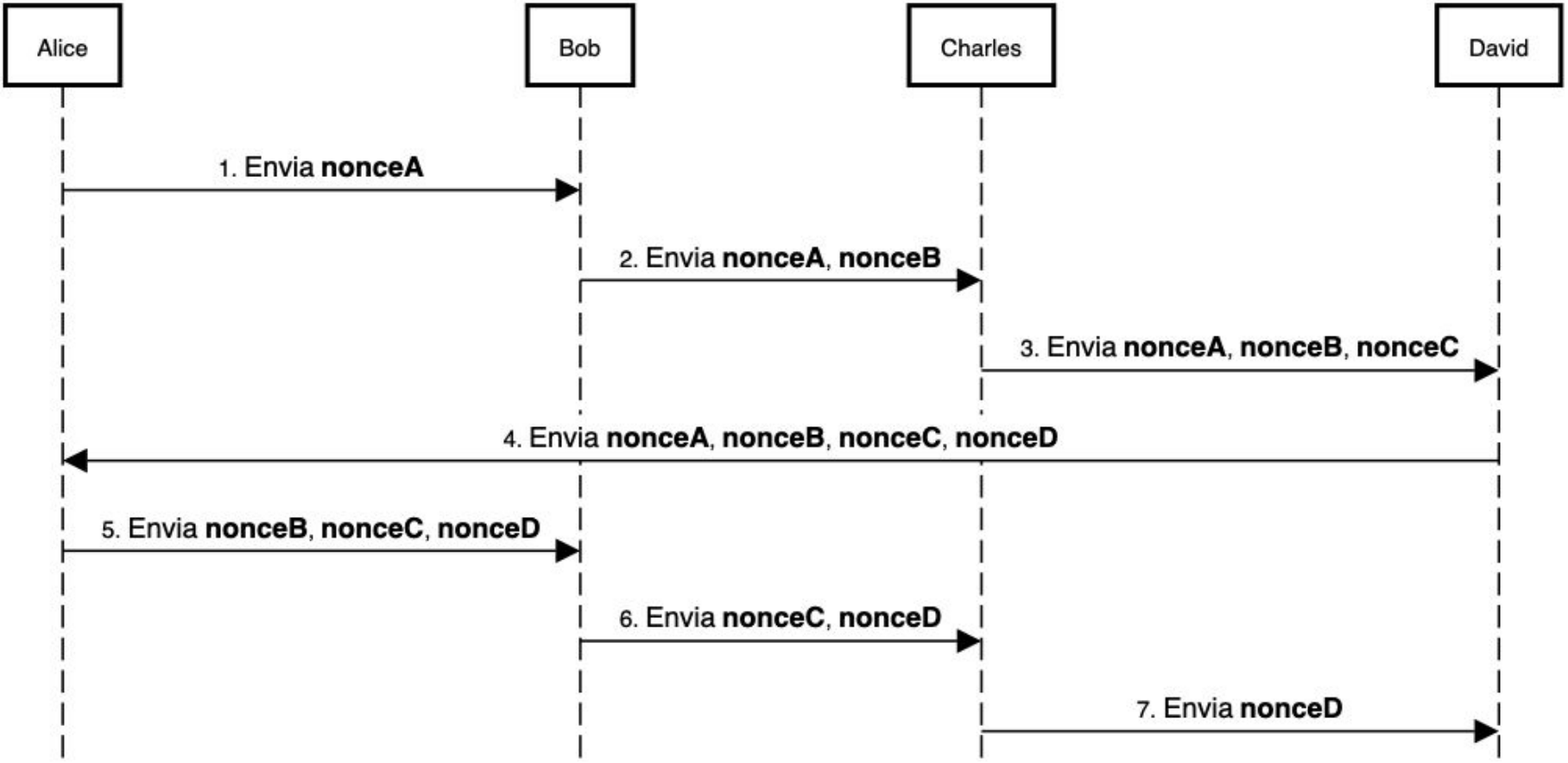
O protocolo 4GNSL (diagrama)



O protocolo 4GNSL (diagrama)



O protocolo 4GNSL (diagrama)



O protocolo 4GNSL (especificação)

1. Alice $\rightarrow$ Bob	$[E_{pk_{Bob}}(\text{Alice,Charles,David,nonceA})]$

O protocolo 4GNSL (especificação)

1. Alice $\rightarrow$ Bob	$[E_{pk_{Bob}}(\text{Alice,Charles,David,nonceA})]$
2. Bob $\rightarrow$ Charles	$[E_{pk_{Charles}}(\text{Alice,Bob,David,nonceA,nonceB})]$

O protocolo 4GNSL (especificação)

1. Alice → Bob	$[E_{pk_{Bob}}(\text{Alice,Charles,David,nonceA})]$
2. Bob → Charles	$[E_{pk_{Charles}}(\text{Alice,Bob,David,nonceA,nonceB})]$
3. Charles → David	$[E_{pk_{David}}(\text{Alice,Bob,Charles,nonceA,nonceB,nonceC})]$

Primeira Fase

O protocolo 4GNSL (especificação)

1. Alice $\rightarrow$ Bob	$[E_{pk_{Bob}}(\text{Alice,Charles,David,nonceA})]$
2. Bob $\rightarrow$ Charles	$[E_{pk_{Charles}}(\text{Alice,Bob,David,nonceA,nonceB})]$
3. Charles $\rightarrow$ David	$[E_{pk_{David}}(\text{Alice,Bob,Charles,nonceA,nonceB,nonceC})]$
4. David $\rightarrow$ Alice	$[E_{pk_{Alice}}(\text{Bob,Charles,David,nonceA,nonceB,nonceC,nonceD})]$

O protocolo 4GNSL (especificação)

1. Alice $\rightarrow$ Bob	$[E_{pk_{Bob}}(\text{Alice,Charles,David,nonceA})]$
2. Bob $\rightarrow$ Charles	$[E_{pk_{Charles}}(\text{Alice,Bob,David,nonceA,nonceB})]$
3. Charles $\rightarrow$ David	$[E_{pk_{David}}(\text{Alice,Bob,Charles,nonceA,nonceB,nonceC})]$
4. David $\rightarrow$ Alice	$[E_{pk_{Alice}}(\text{Bob,Charles,David,nonceA,nonceB,nonceC,nonceD})]$
5. Alice $\rightarrow$ Bob	$[E_{pk_{Bob}}(\text{nonceB,nonceC,nonceD})]$

O protocolo 4GNSL (especificação)

1. Alice → Bob	$[E_{pk_{Bob}}(\text{Alice,Charles,David,nonceA})]$
2. Bob → Charles	$[E_{pk_{Charles}}(\text{Alice,Bob,David,nonceA,nonceB})]$
3. Charles → David	$[E_{pk_{David}}(\text{Alice,Bob,Charles,nonceA,nonceB,nonceC})]$
4. David → Alice	$[E_{pk_{Alice}}(\text{Bob,Charles,David,nonceA,nonceB,nonceC,nonceD})]$
5. Alice → Bob	$[E_{pk_{Bob}}(\text{nonceB,nonceC,nonceD})]$
6. Bob → Charles	$[E_{pk_{Charles}}(\text{nonceC,nonceD})]$

O protocolo 4GNSL (especificação)

1. Alice → Bob	$[E_{pk_{Bob}}(\text{Alice,Charles,David,nonceA})]$
2. Bob → Charles	$[E_{pk_{Charles}}(\text{Alice,Bob,David,nonceA,nonceB})]$
3. Charles → David	$[E_{pk_{David}}(\text{Alice,Bob,Charles,nonceA,nonceB,nonceC})]$
4. David → Alice	$[E_{pk_{Alice}}(\text{Bob,Charles,David,nonceA,nonceB,nonceC,nonceD})]$
5. Alice → Bob	$[E_{pk_{Bob}}(\text{nonceB,nonceC,nonceD})]$
6. Bob → Charles	$[E_{pk_{Charles}}(\text{nonceC,nonceD})]$
7. Charles → David	$[E_{pk_{David}}(\text{nonceD})]$

O protocolo 4GNSL (especificação)

1. Alice → B	,Charles,David,nonceA)]
2. Bob → Ch	ice,Bob,David,nonceA,nonceB)]
3. Charl →	ce,Bob,Charles,nonceA,nonceB,nonceC)]
4. David → Alice	$[E_{pk_{Alice}}$(Bob,Charles,David,nonceA,nonceB,nonceC,nonceD)]
5. Alice → Bob	$[E_{pk_{Bob}}$(nonceB,nonceC,nonceD)]
6. Bob → Charles	$[E_{pk_{Charles}}$(nonceC,nonceD)]
7. Charles → David	$[E_{pk_{David}}$(nonceD)]

Segunda Fase

O protocolo 4GNSL (semântica Scyther)

Protocolo na semântica Scyther:

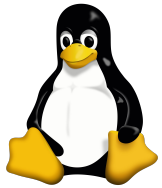
https://s4a.in/github

```
d:~$ cd ~/
d:~$ git clone https://github.com/scyther-lea/errc2020.git
d:~$ cd ~/errc2020/scyther
d:~$ vim protocolo_4gnsl.spdl
```

O protocolo 4GNSL (verificação

```
./scyther.py --auto-claims --all-attacks --max-runs=7 protocolo_4gnsl.spdl

Verification results:
claim id [4GNSL,Alice1], Secret(nonceA)    : Proof of correctness
claim id [4GNSL,Alice2], Secret(nonceD)    : No attacks within bounds.
claim id [4GNSL,Alice3], Secret(nonceC)    : No attacks within bounds.
claim id [4GNSL,Alice4], Secret(nonceB)    : Proof of correctness.
claim id [4GNSL,Alice5], Alive             : Proof of correctness.
claim id [4GNSL,Alice6], Weakagree         : Proof of correctness.
claim id [4GNSL,Alice7], Niagree           : Proof of correctness.
claim id [4GNSL,Alice8], Nisynch           : Proof of correctness.
claim id [4GNSL,Bob1], Secret(nonceB)      : No attacks within bounds.
claim id [4GNSL,Bob2], Secret(nonceD)      : No attacks within bounds.
claim id [4GNSL,Bob3], Secret(nonceC)      : No attacks within bounds.
claim id [4GNSL,Bob4], Secret(nonceA)      : No attacks within bounds.
claim id [4GNSL,Bob5], Alive               : No attacks within bounds.
claim id [4GNSL,Bob6], Weakagree           : No attacks within bounds.
claim id [4GNSL,Bob7], Niagree             : No attacks within bounds.
claim id [4GNSL,Bob8], Nisynch             : No attacks within bounds.
```



O protocolo 4GNSL (aprovado Scyther)

1. Alice → Bob	$[E_{pk_{Bob}}$(Alice,Charles,David,nonceA)]
2. Bob → Charles	$[E_{pk_{Charles}}$(Alice,Bob,David,nonceA,nonceB)]
3. Charles → David	$[E_{pk_{David}}$(Alice,Bob,Charles,nonceA,nonceB,nonceC)]
4. David → Alice	$[E_{pk_{Alice}}$(Bob,Charles,David,nonceA,nonceB,nonceC,nonceD)]
5. Alice → Bob	$[E_{pk_{Bob}}$(nonceB,nonceC,nonceD)]
6. Bob → Charles	$[E_{pk_{Charles}}$(nonceC,nonceD)]
7. Charles → David	$[E_{pk_{David}}$(nonceD)]

APPROVED

Roteiro

- ✓ Introdução
- ✓ A ferramenta Scyther
- ✓ O protocolo ACS
- ✓ O protocolo WMF
- ✓ O protocolo NS
- ✓ O protocolo GNSL
- ❑ **Considerações finais**

Considerações finais

- Atualização de Chave Simétrica (ACS)
- Wide Mouth Frog (WMF)
- Needham-Schroeder (NS)
- Needham-Schroeder-Lowe (NSL)
- Generalized NS-Lowe (GNSL)

Considerações finais

- Protocolos de segurança são cruciais
- Verificação automática é importante
- Falha do NS descoberta 17 anos depois
- Ferramentas: **Scyther**, Pro-Verif, CryptoVerif, AVISPA, Tamarin Prover, Coq, ...

Roteiro

- ✓ Introdução
- ✓ A ferramenta Scyther
- ✓ O protocolo ACS
- ✓ O protocolo WMF
- ✓ O protocolo NS
- ✓ O protocolo GNSL
- ✓ Considerações finais

Obrigado!

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