Towards evolving specs of security protocols

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(based on joint work with A. Datta, J. Mitchell, D. Smith…)

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Claim

Security Engineering

is a part of

Software Engineering

Claim

- it is helpful to analyze:
  - protocols in context of architectures
  - security as a part of of high assurance
  - malicious attackers on connectors together with unspecified environments of components
- both SE and SE are concerned with
  - distributed,
  - multi-layered,
  - heterogenous complex systems…

Outline

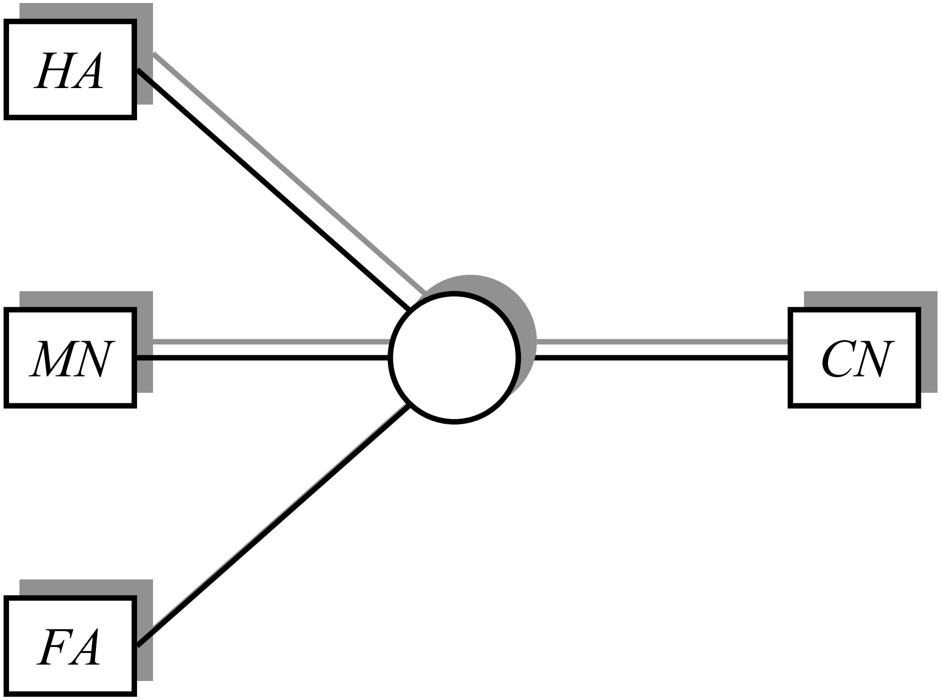
- Mobile proposals:
  - IPv4 *vs* IPv6
- Problem:
  - remote redirection (traffic hijacking)
- Adding authentication:
  - espec transformation
- Variations and ongoing work

Papers

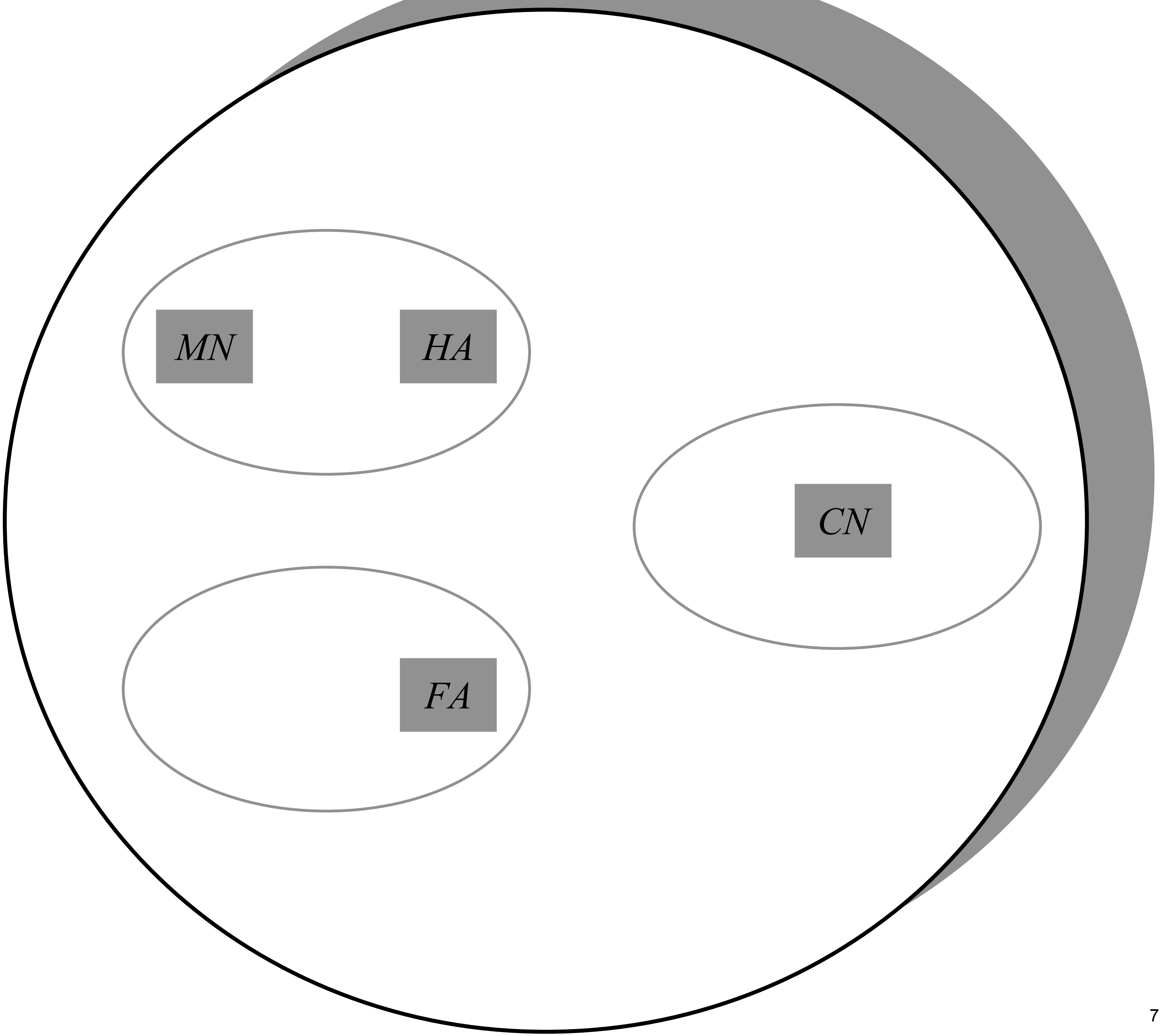
- Authentication for Mobile IPv6
  - with A. Datta, J. Mitchell and F. Muller
- Composition and refinement of behavioral specifications
  - with D. Smith
- Guarded transitions in evolving specifications
  - with D. Smith

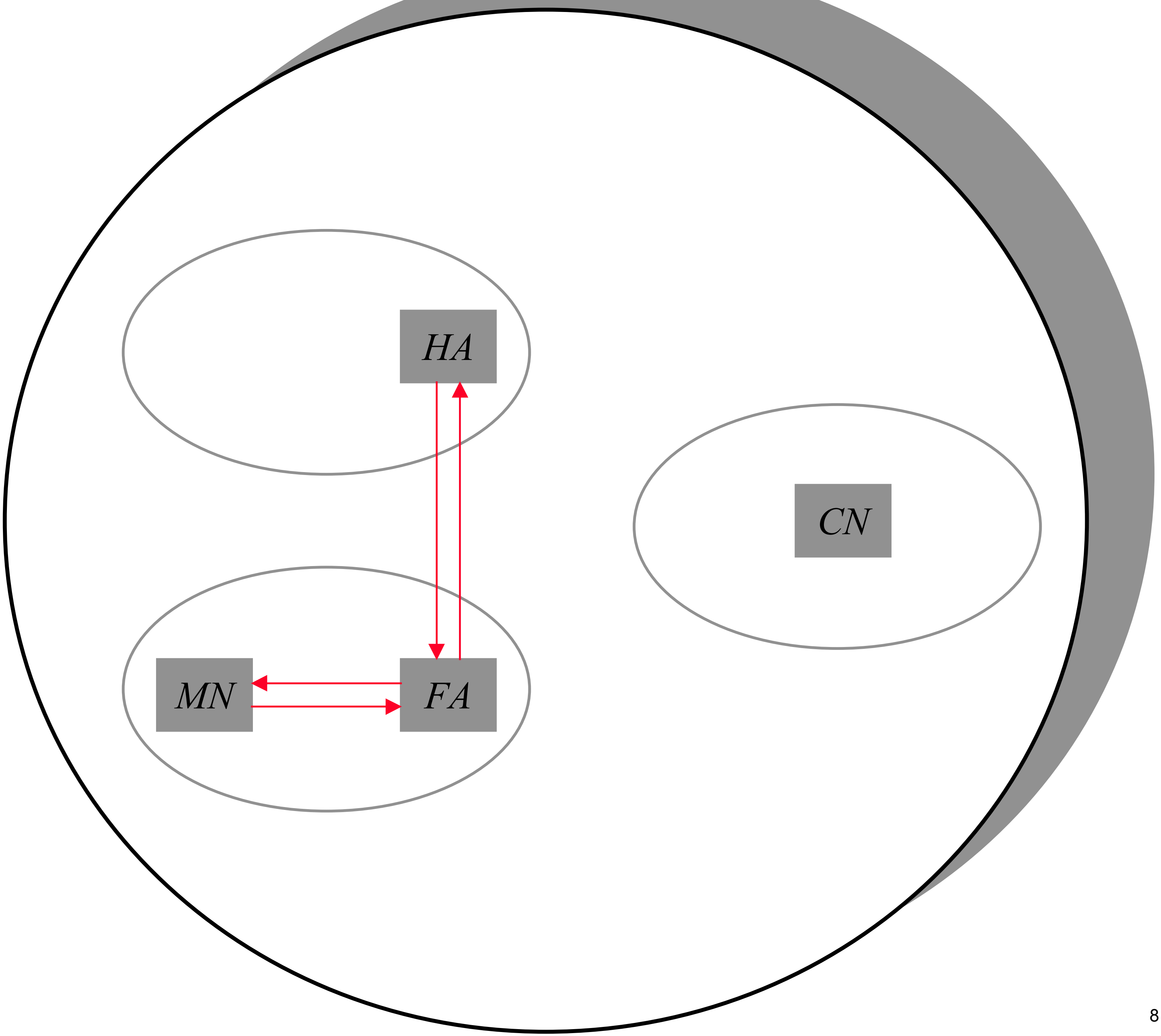
http://www.kestrel.edu/users/pavlovic/

Mobile IPv4



initial architecture


MN
HA
CN
FA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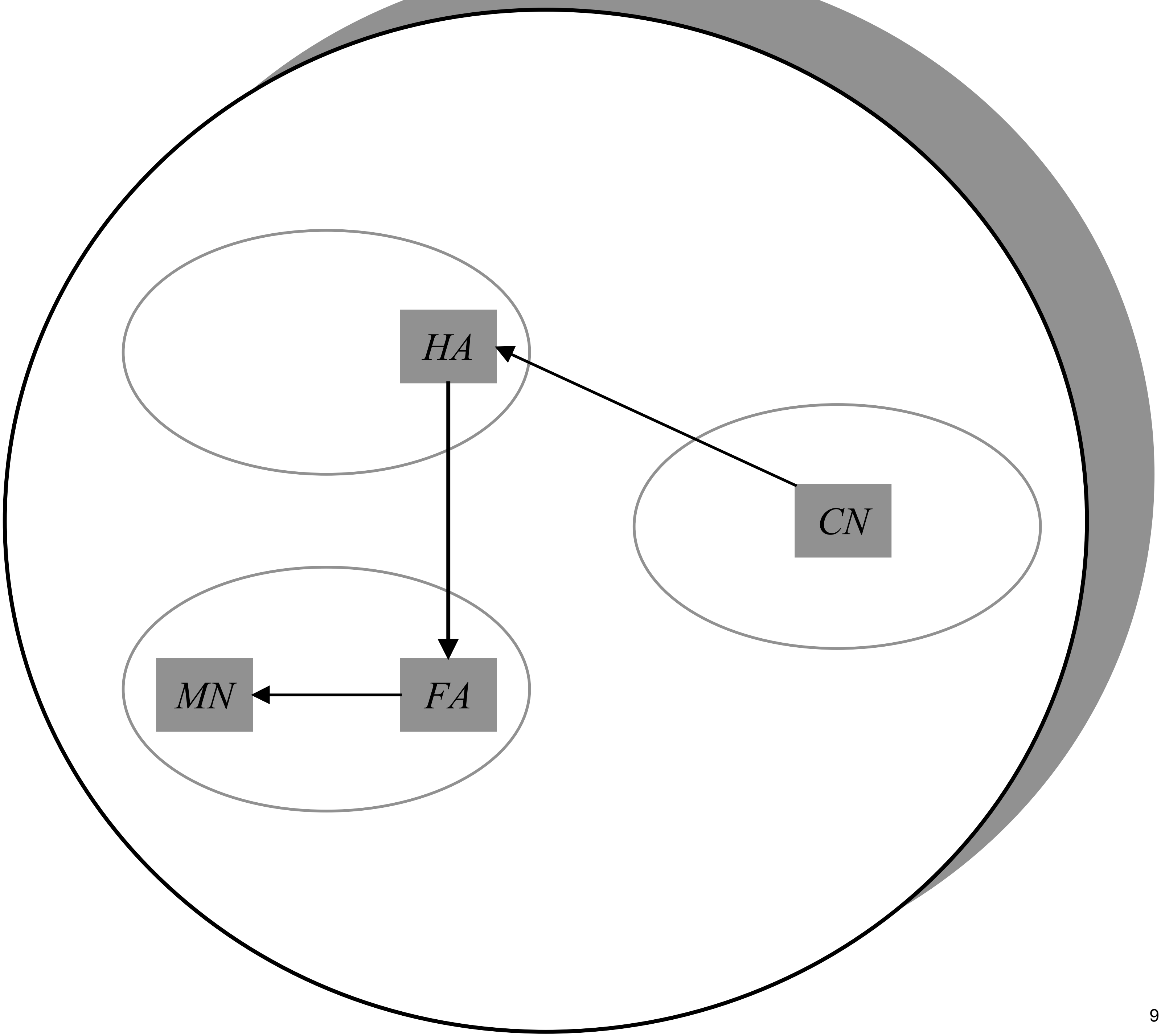
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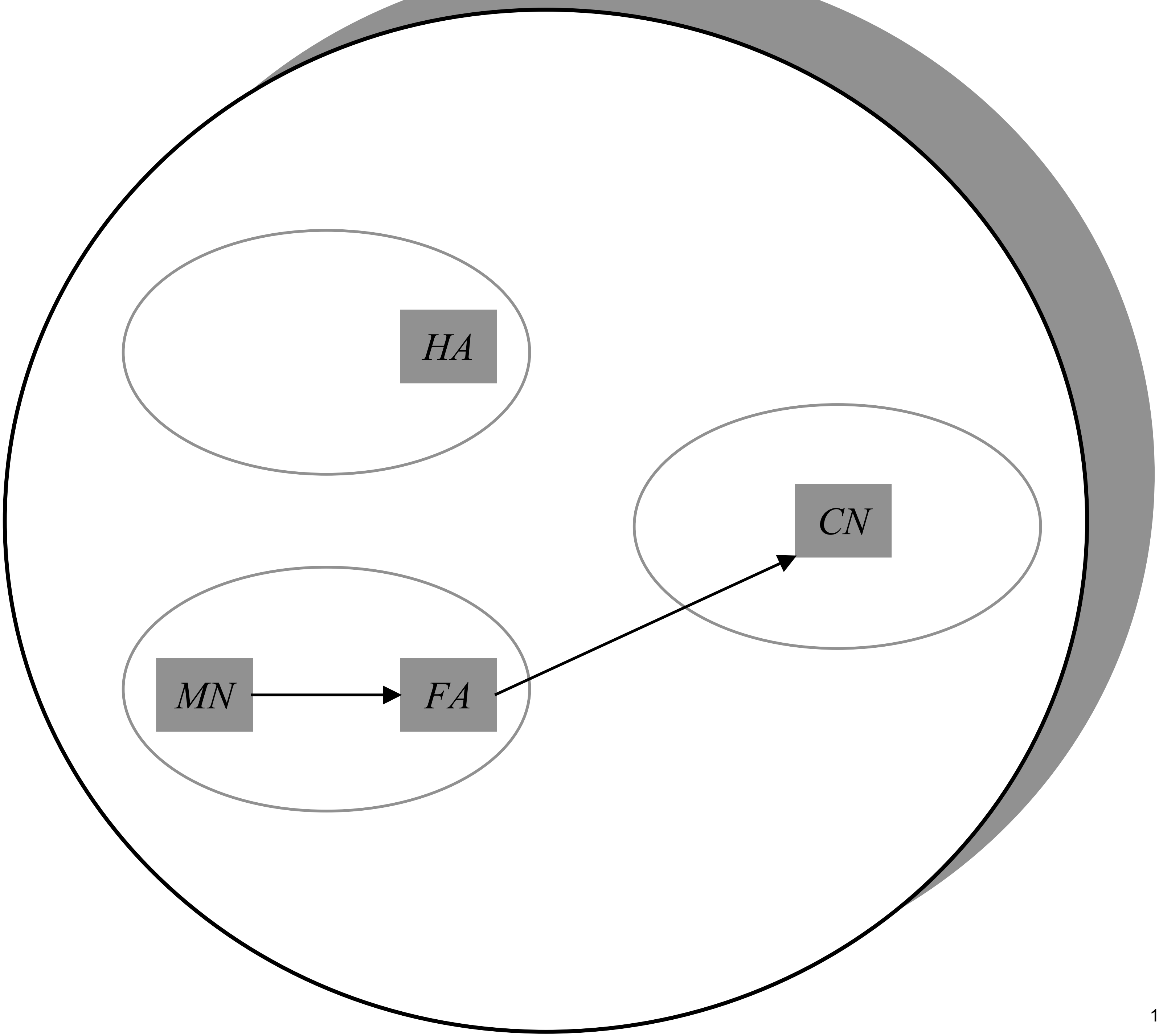
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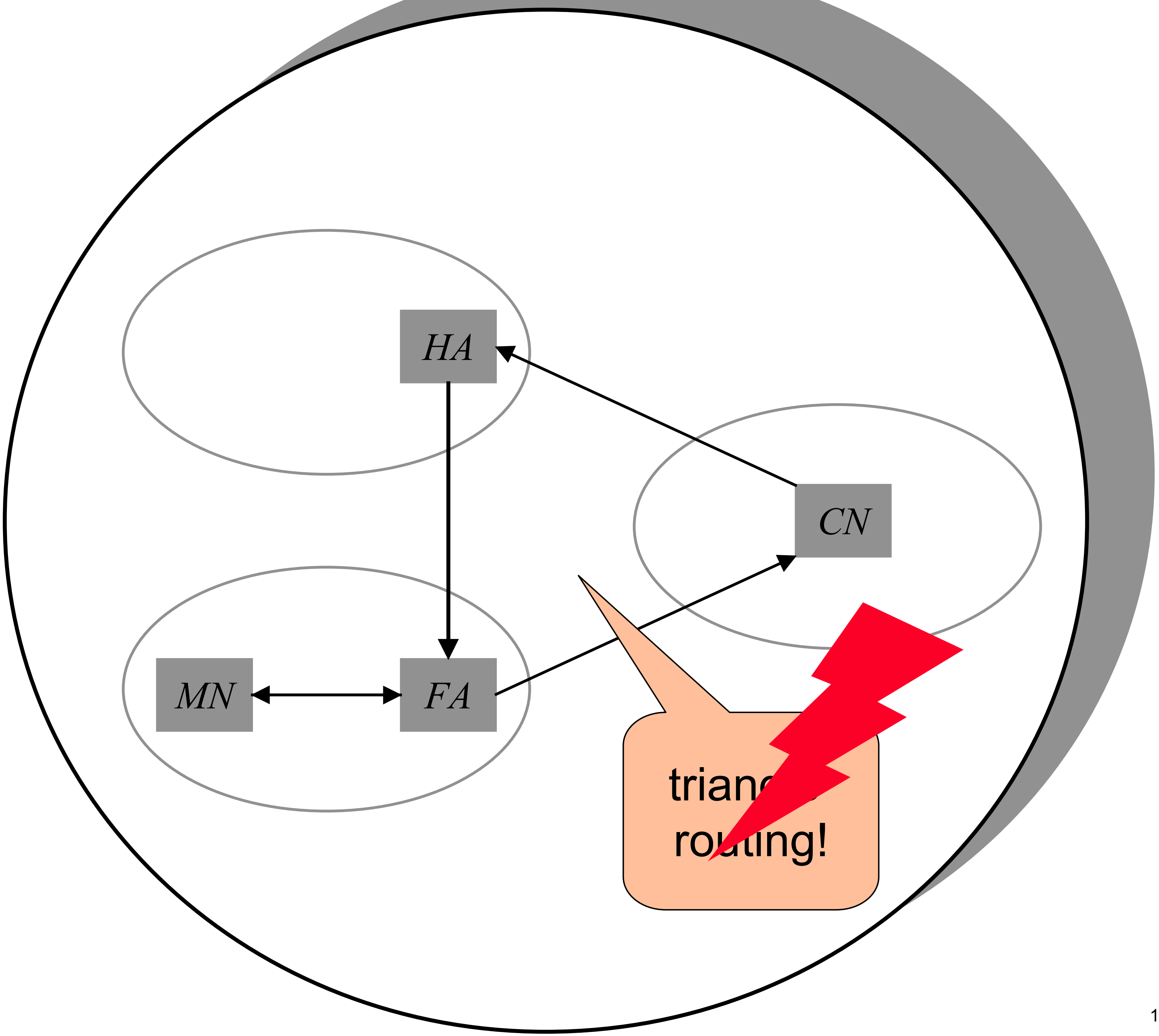
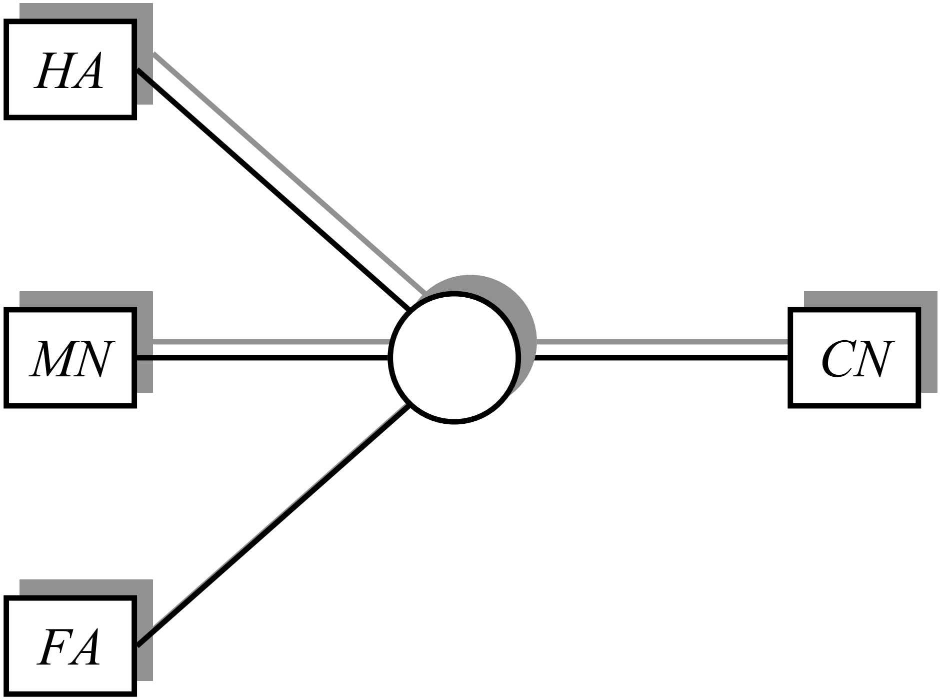

HA
CN
MN
FA
triangle
routing!

Mobile IPv4



session architecture

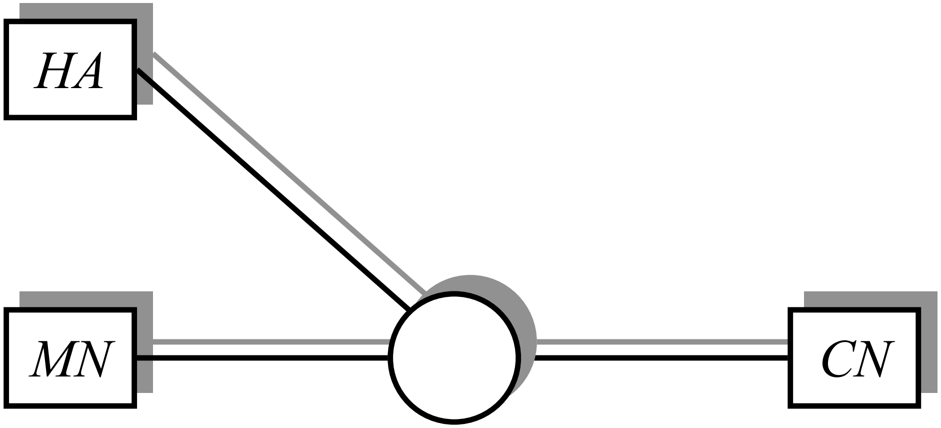
Mobile IPv6

- avoid triangle routing:
  - use IPv6 Routing Header and tunneling
- minimize
  - network partitioning
  - computational load on:
    - routers
    - nodes: no expensive encryptions or decryptions
  - number of messages
  - need for infrastructure: no global PKI
- maximize
  - performance and availability: no DoS
  - end-to-end security: authenticate location information

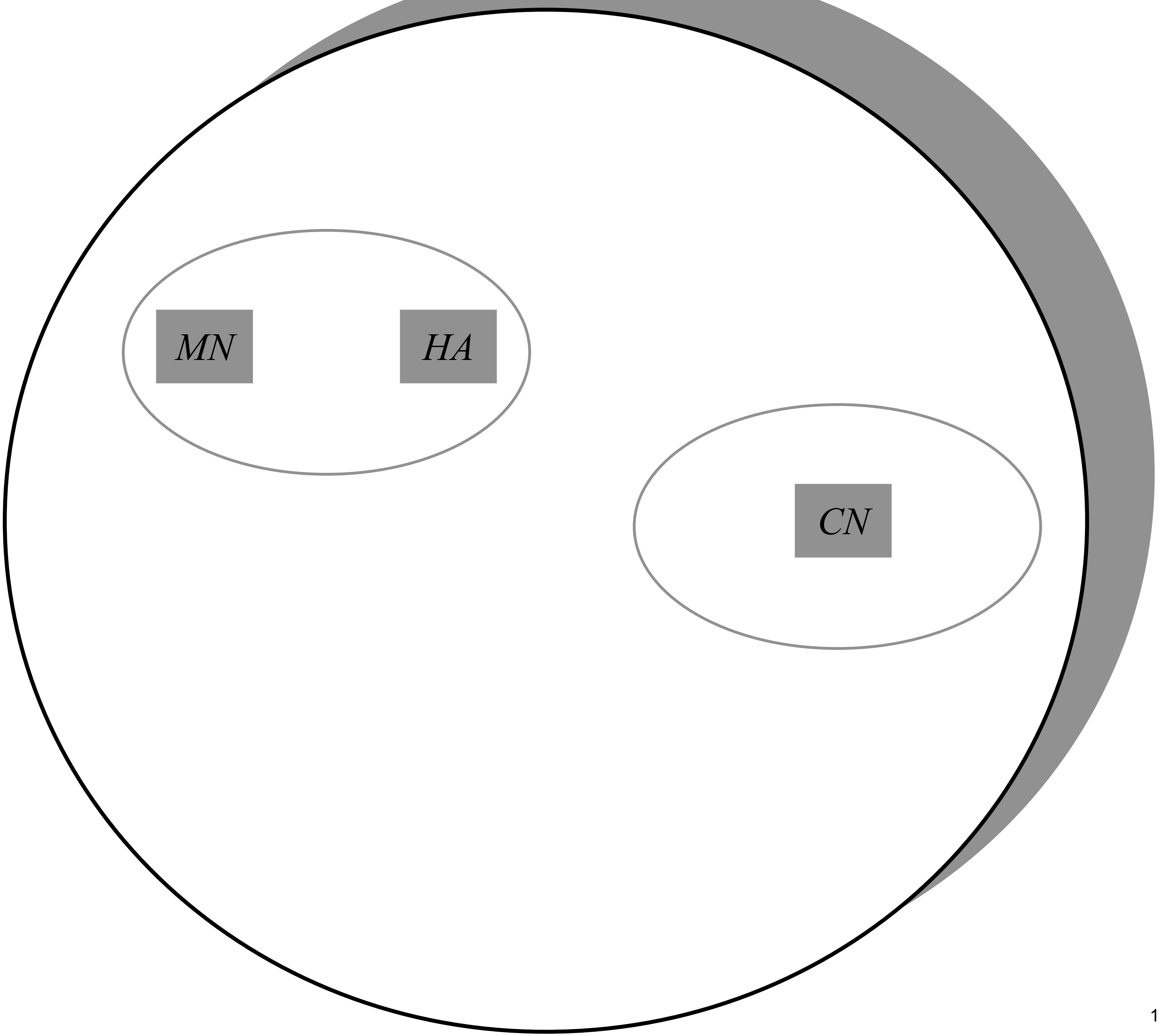
Mobile IPv6

- home address
  - the node is always addressed by the same IP number
- care-of addresses (one or more)
  - bind dynamically to different subnet IP numbers
    - » all packets containing the binding information must be authenticated
    - » authentication relies upon previously established security associations
- Binding Update/Acknowledgement
  - realized through Destination Options Headers
  - Binding Cache integrated with Destination Cache

Mobile IPv6 proposal



initial architecture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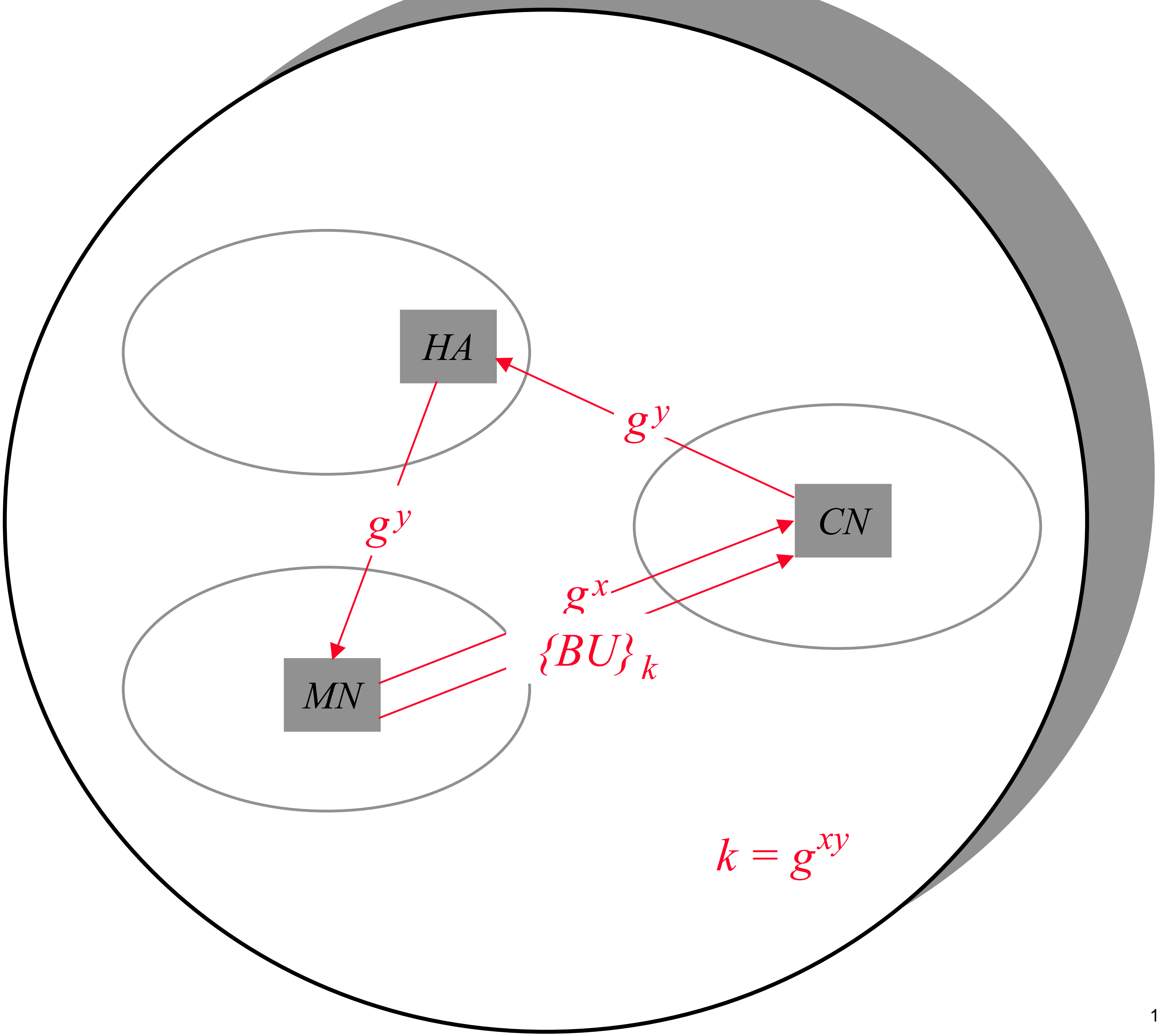
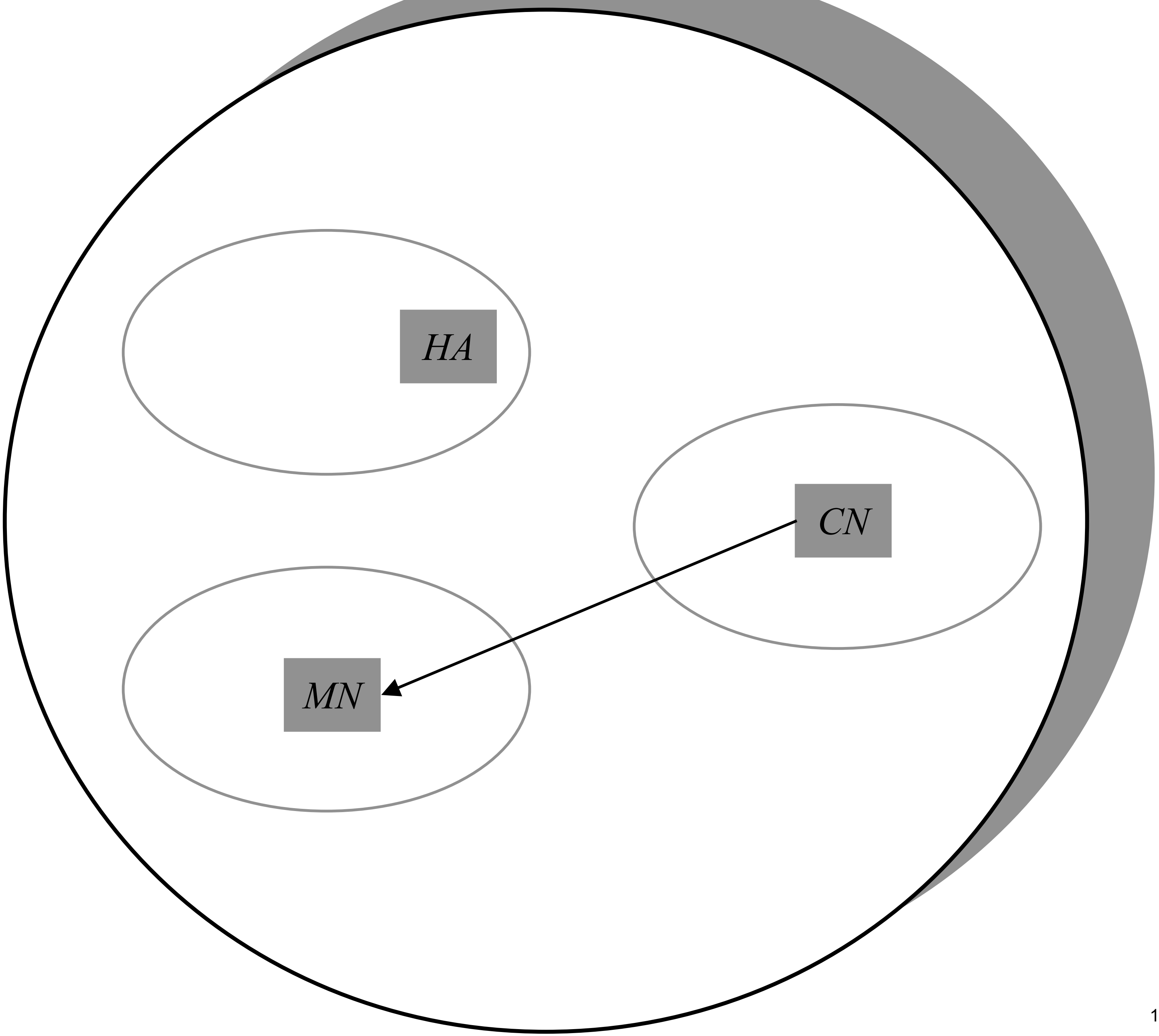
HA
CN


HA
g^y
g^y
CN
g^x
MN
$\{BU\}_k$
$k = g^{xy}$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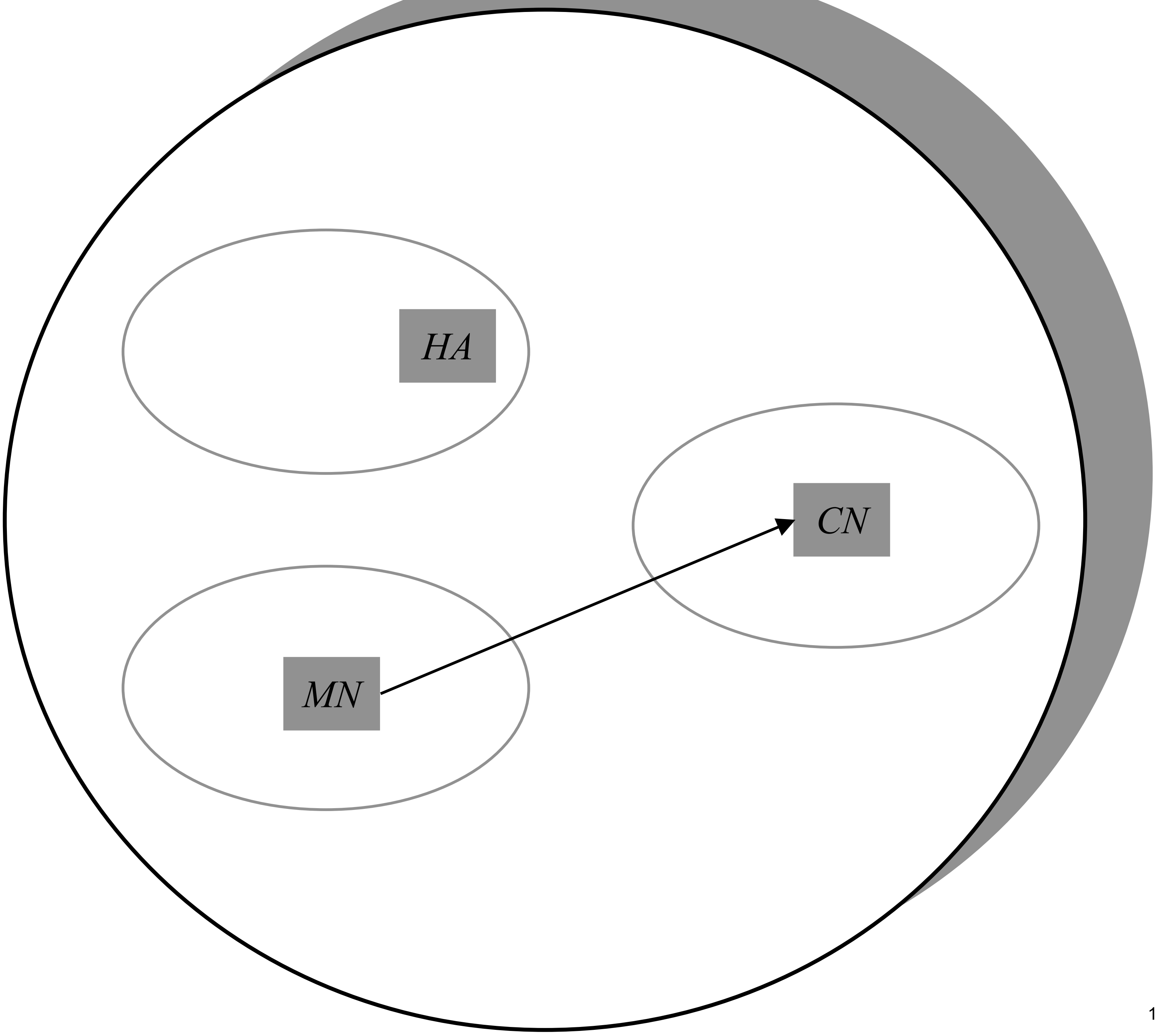
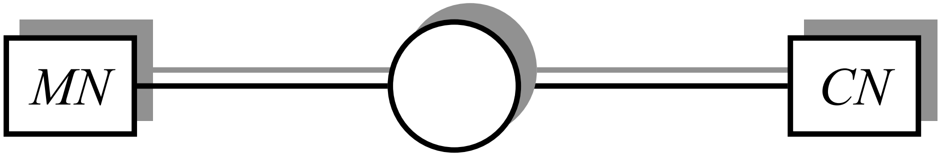
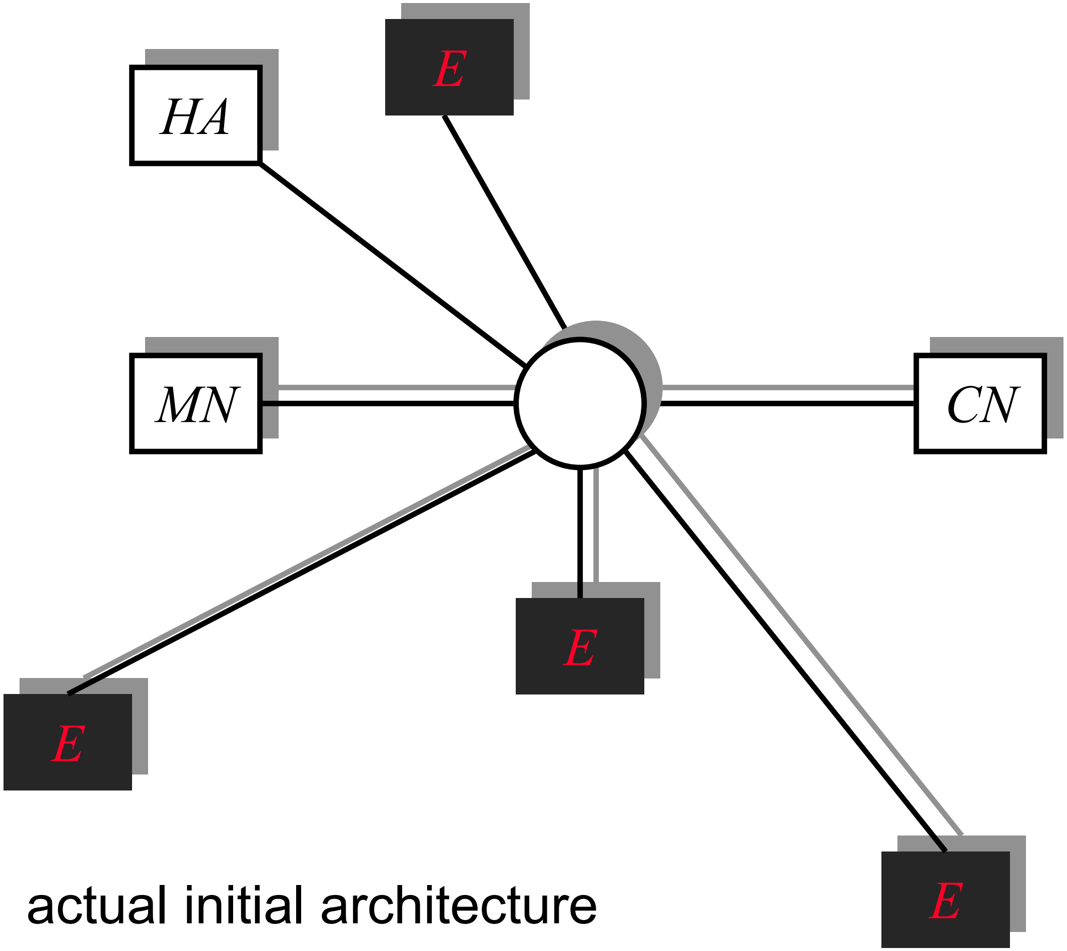

HA
CN
MN

Mobile IPv6 proposal

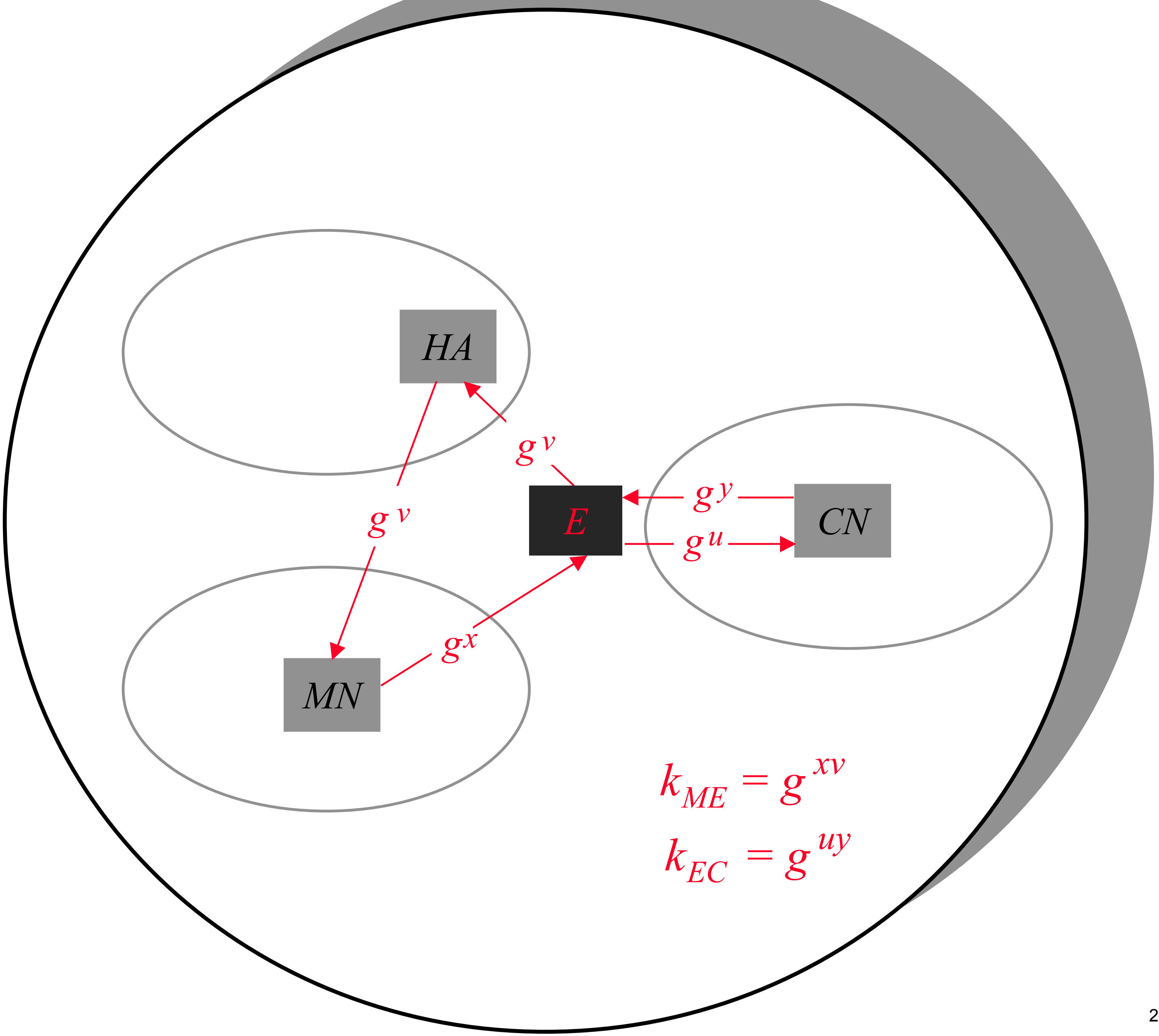


session architecture

Mobile IPv6 proposal



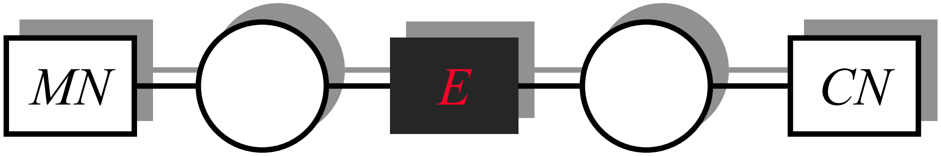
actual initial architecture



$$k_{ME} = g^{xv}$$

$$k_{EC} = g^{uy}$$

Mobile IPv6 proposal



possible session architecture

Task

Use especs

to add authentication!

Task

- Assess tradeoff between
  - maximizing strength of authentication
  - minimizing need for infrastructure

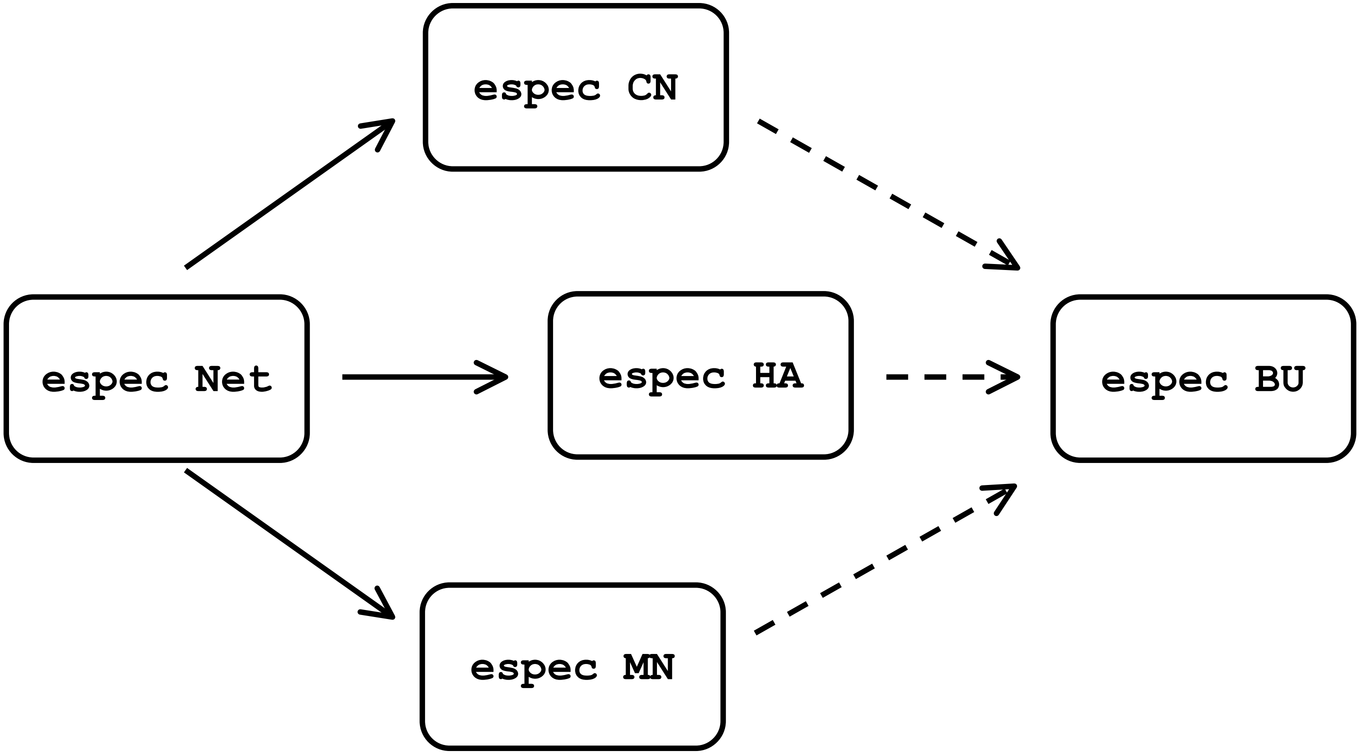
MN’s view

```
espec MN
```

CN’s view

```
espec CN
```

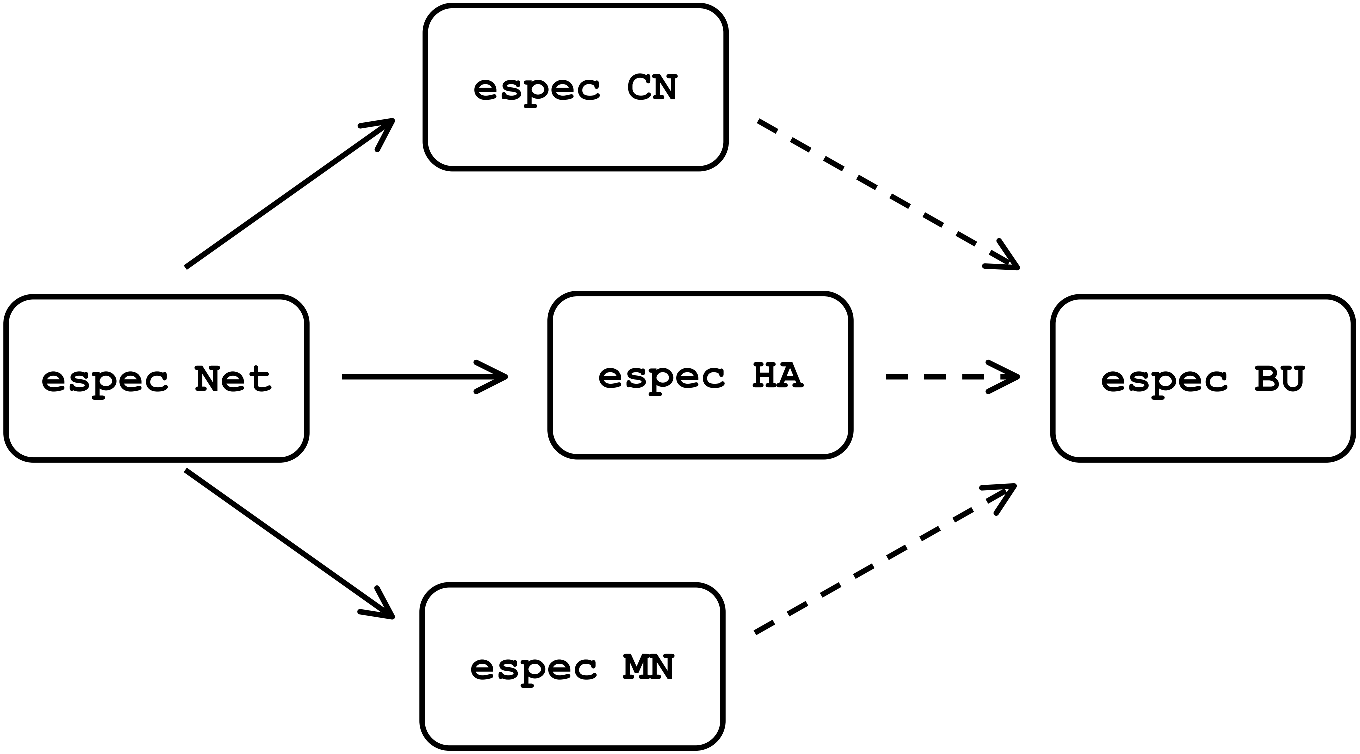
BU architecture



(aspects of especs)

- genericity
  - all agents are instances of cord espec
- automated
  - composition of agents
  - trace generation
- support for formal analysis
  - model checking
  - theorem proving
  - invariant generation

BU architecture



BU architecture

diag BU

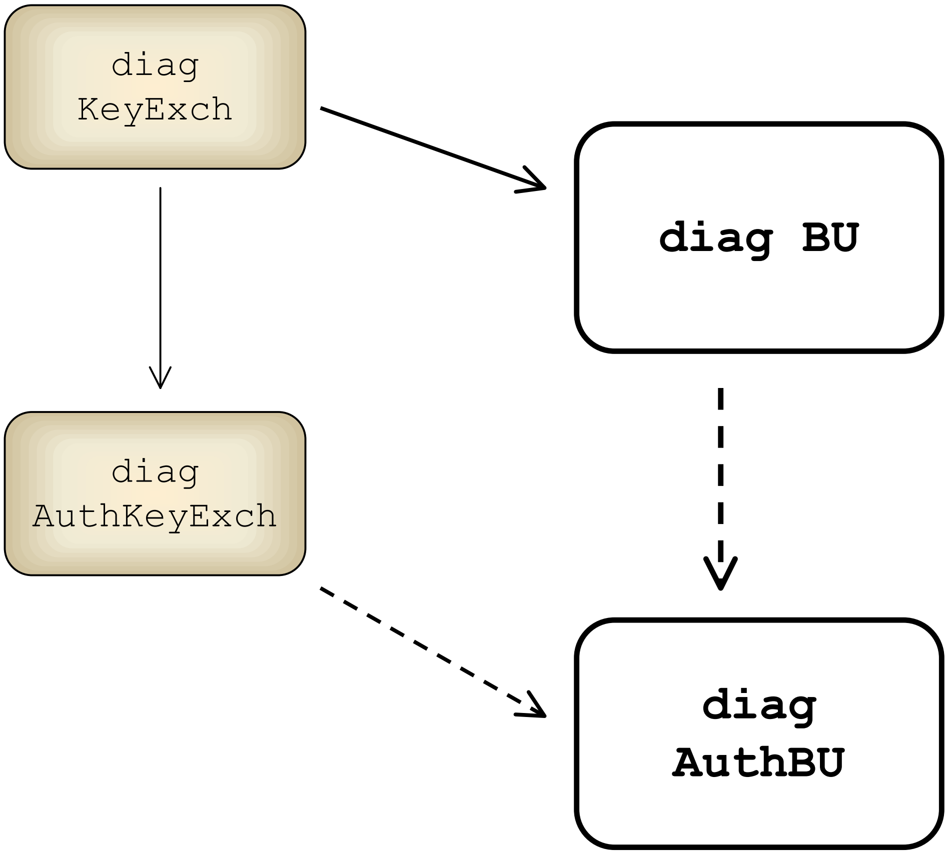
(aspects of especs)

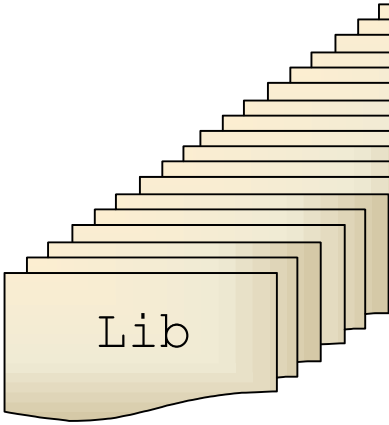
- adjustable abstraction level
- stratification:
  - agents: process calculus
  - protocols: especs
  - architectures: diagrams
    - network connectors and components
    - infrastructure and chain of trust
    - information flow
    - …

BU architecture

`diag BU`

BU refinement

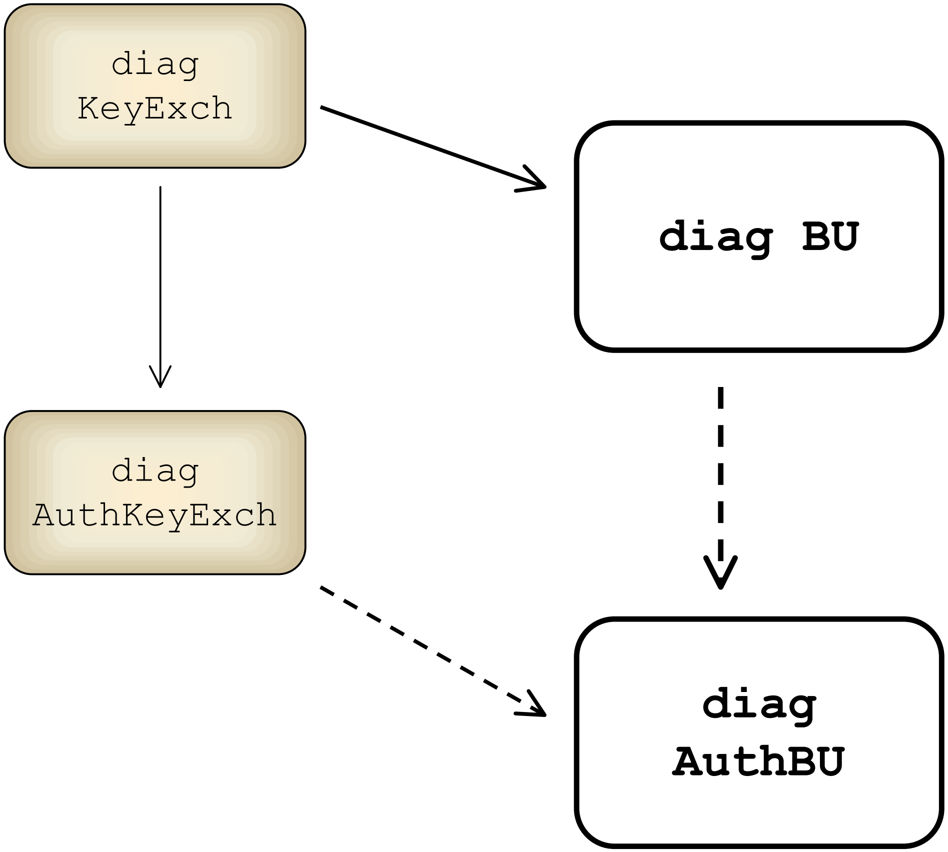


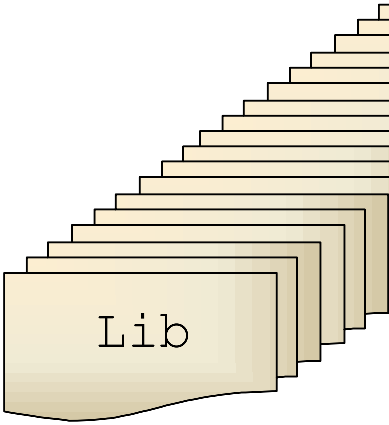


(aspects of especs)

- development (programming, generation)
  - – top-down: refinement
    - » morphisms: inheritance, genericity
  - – bottom-up: composition
    - » pushouts
    - » emergent and vanishing properties
    - » game theory, linear logic (strategies)
  - – program transformation
    - » authentication compiler (Bellare-Canetti-Krawczyk)
    - » optimization
  - – adaptation
    - » specification-carrying software

BU refinement





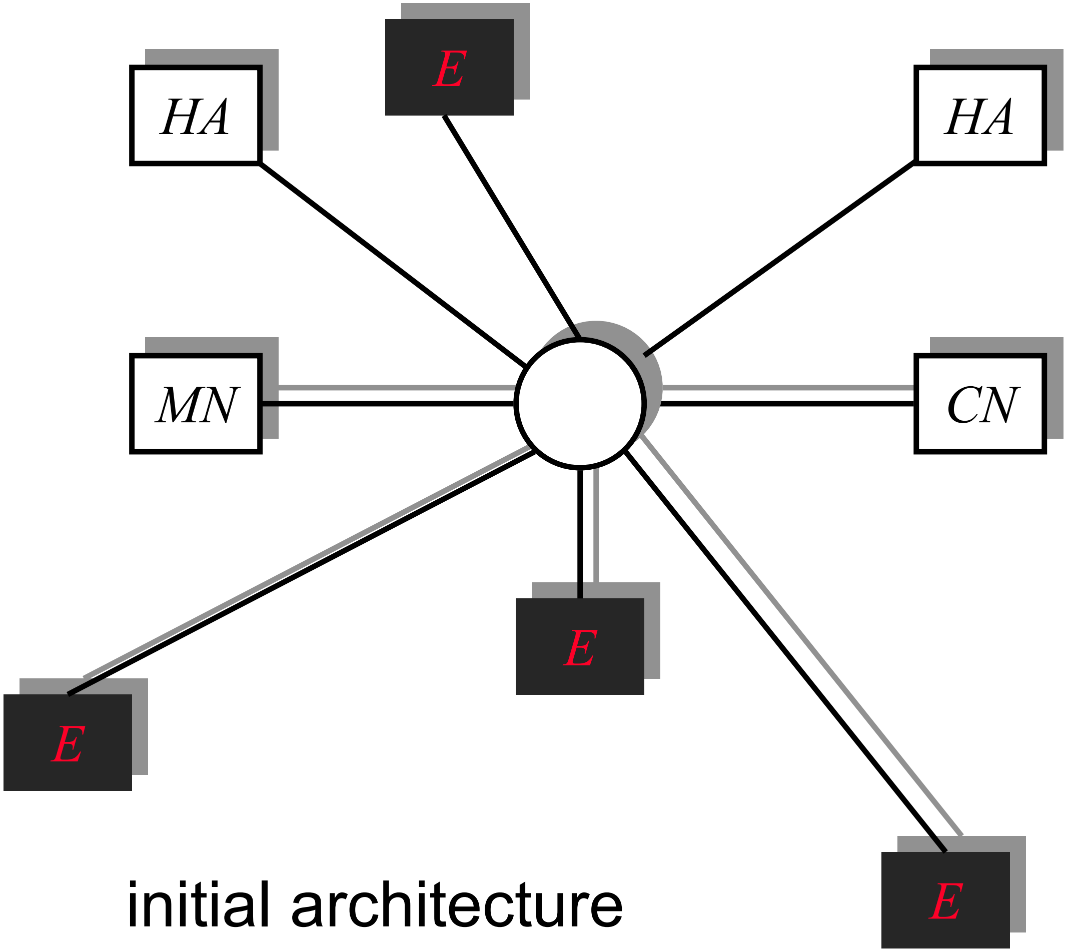
AuthBU architecture

diag
AuthBU

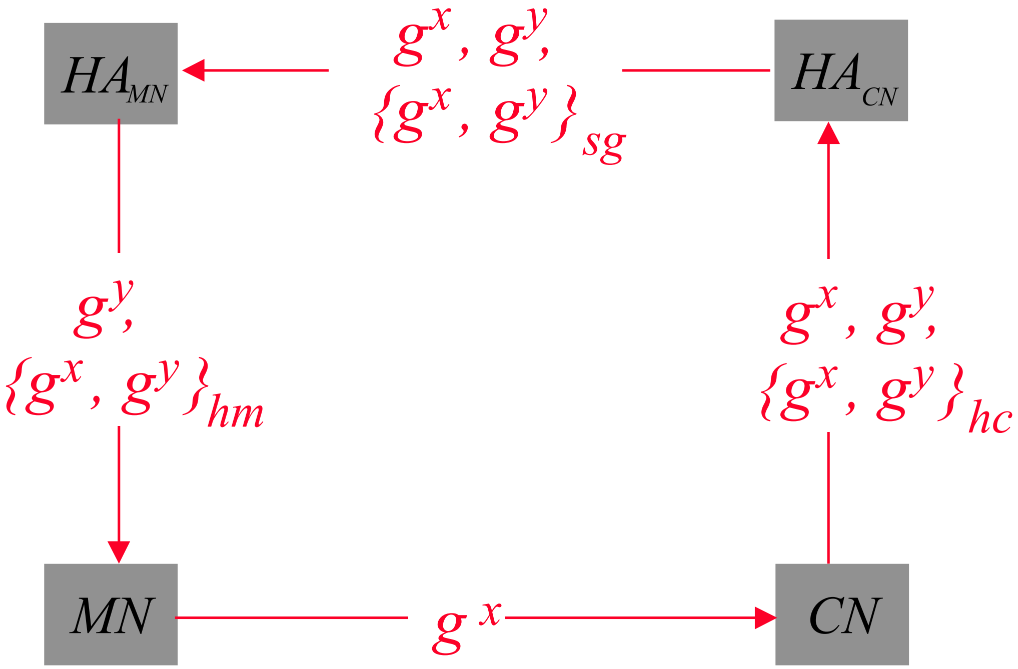
AuthMN’s view

```
espec
AuthMN
```

Authenticated MIPv6



initial architecture



HA_{MN}

HA_{CN}

MN

CN

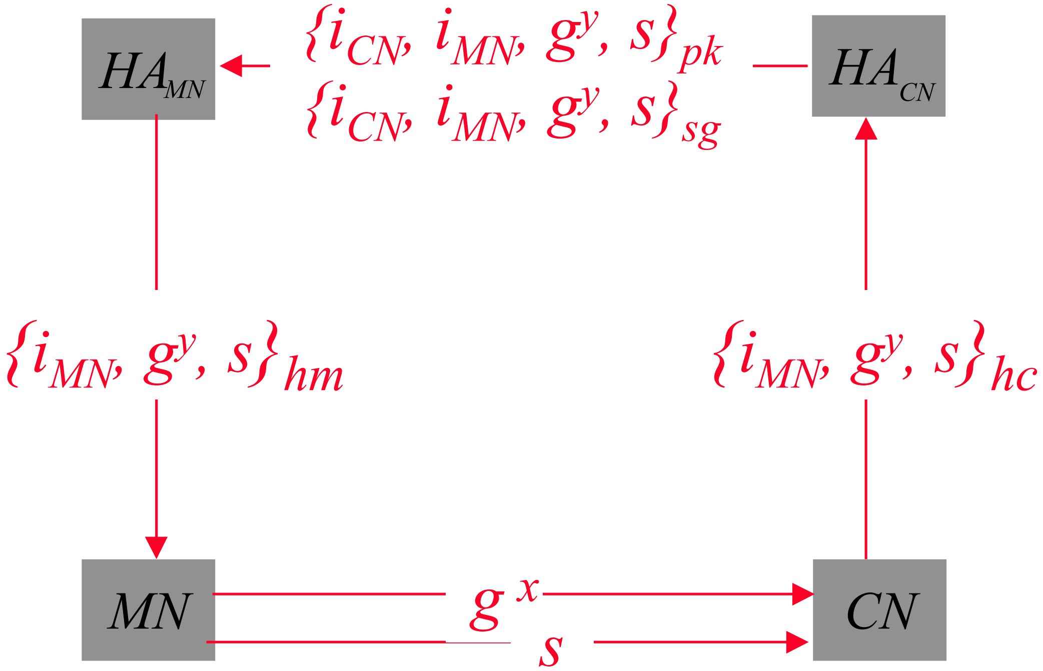
g^x

$g^x, g^y, \{g^x, g^y\}_{hc}$

$g^x, g^y, \{g^x, g^y\}_{sg}$

$g^y, \{g^x, g^y\}_{hm}$

$$k = g^{xy}$$



HA_{MN}

HA_{CN}

$\{i_{CN}, i_{MN}, g^y, s\}_{pk}$

$\{i_{CN}, i_{MN}, g^y, s\}_{sg}$

$\{i_{MN}, g^y, s\}_{hm}$

$\{i_{MN}, g^y, s\}_{hc}$

MN

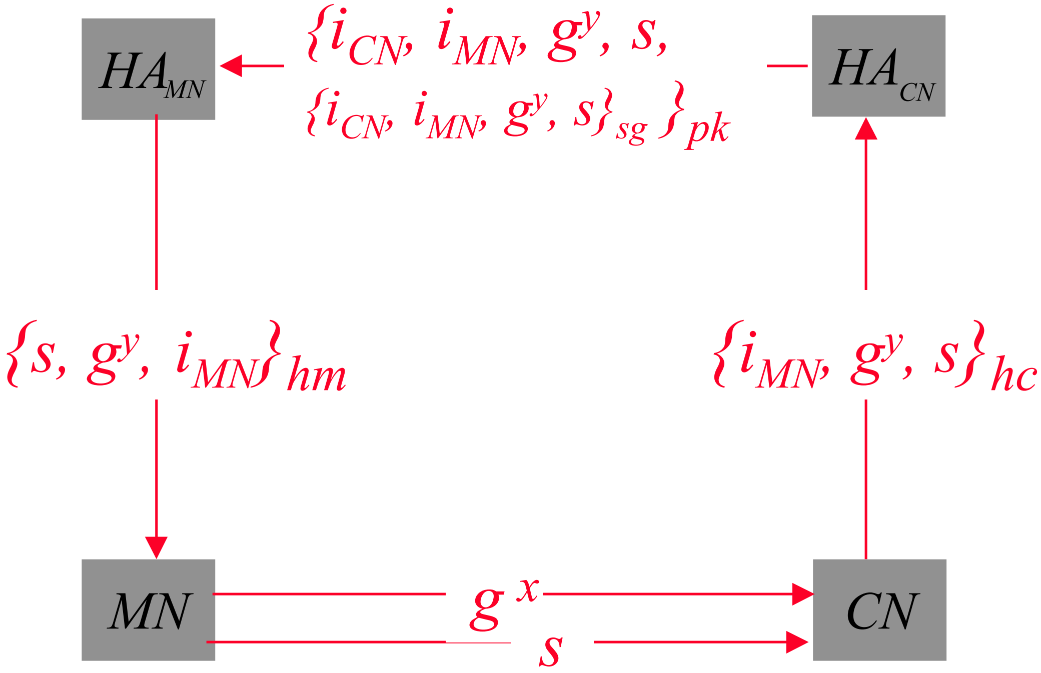
CN

g^x

s

$k = g^{xy}$

$s = \{i_{CN}, i_{MN}, g^x, g^y\}_k$



HA_{MN}

HA_{CN}

$\{i_{CN}, i_{MN}, g^y, s, \{i_{CN}, i_{MN}, g^y, s\}_{sg} \}_{pk}$

$\{s, g^y, i_{MN}\}_{hm}$

$\{i_{MN}, g^y, s\}_{hc}$

MN

CN

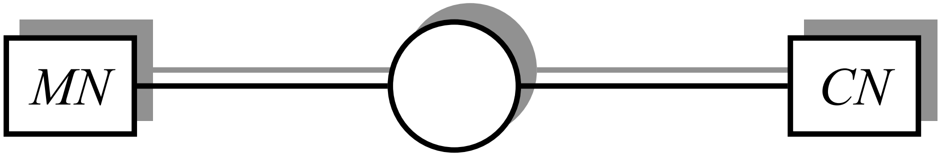
g^x

s

$$k = g^{xy}$$

$$s = \{i_{CN}, i_{MN}, g^x, g^y\}_k$$

Authenticated MIPv6



assured session architecture

Variations

- weaker authentications:
  - one-way: no PKI, just certificates, or AAA - no anonymity
  - first time unauthenticated (like SSH), then chained hashing
- stronger authentications:
  - privacy
  - anonymity, non-repudiation
- dynamic infrastructure
  - no shared secret: databases of “fingerprints”
  - authenticating by non-forgeable capability
  - authenticating by divided secret

(aspects of especs)

- additional aspects:
  - – information flow
  - – information hiding
  - – cryptography
  - – …

Ongoing work

IMPLEMENT the tool!

Papers

- Authentication for Mobile IPv6
  - with A. Datta, J. Mitchell and F. Muller
- Composition and refinement of behavioral specifications
  - with D. Smith
- Guarded transitions in evolving specifications
  - with D. Smith

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(cord spaces)

(names) $N ::= X \mid A$

(terms) $t ::= x \mid a \mid N \mid t,\ldots,t \mid {}_N\{t\}$

(actions) $a ::= \langle t\rangle \mid (x) \mid (t/p(x))$

(strands) $S ::= aS$

(cords) $C ::= [S]_{\approx}$

$FV(t) = \emptyset$

(interaction) $[(x)R] \otimes [\langle t\rangle S] \ldots \quad \rhd\rhd \quad [R(t/x)] \otimes [S] \ldots$

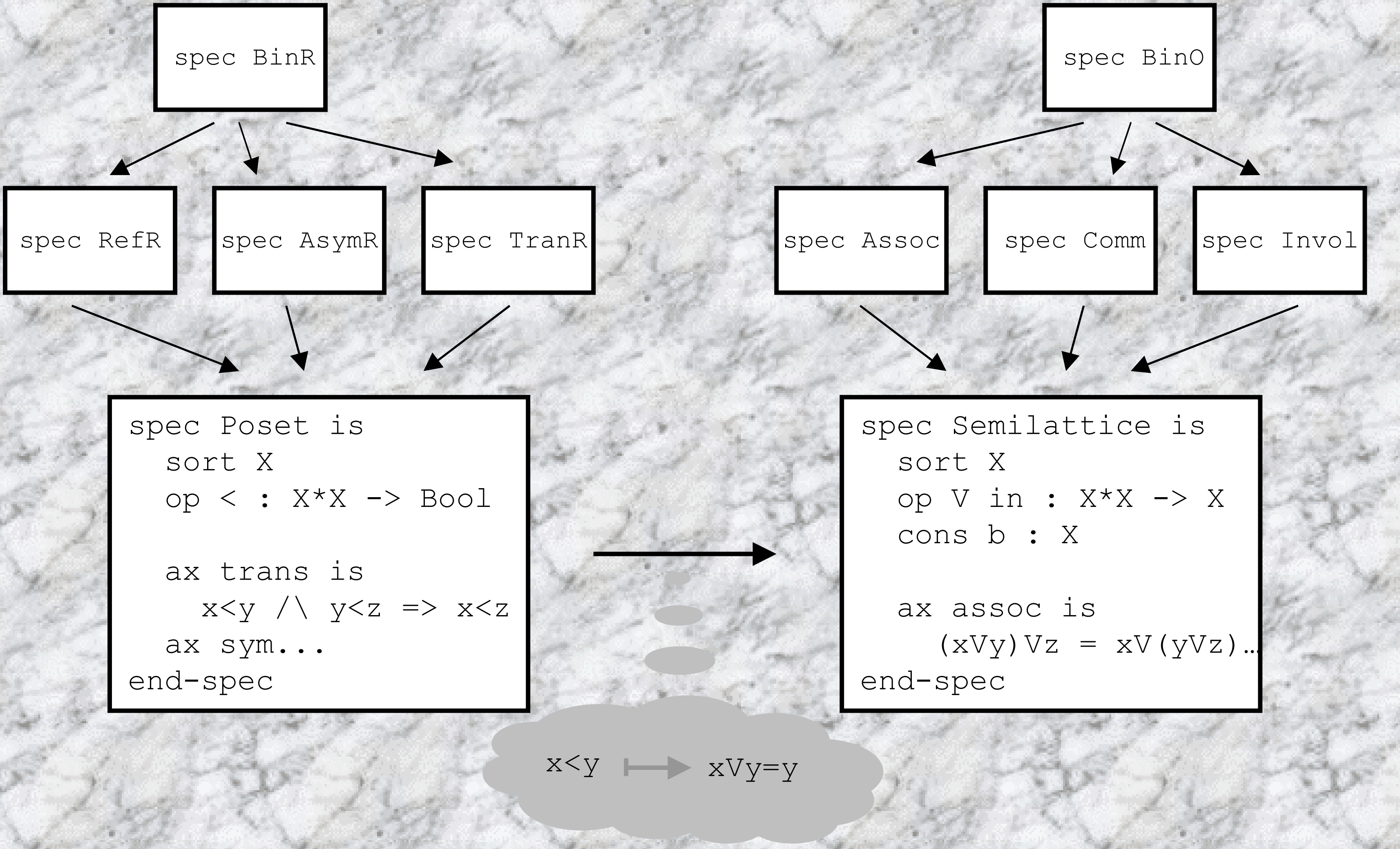
(reaction) $[(p(t)/p(x))R] \ldots \quad \rhd\rhd \quad [R(t/x)] \ldots$

$FV(t) = \emptyset$

What are especs?

- diagrams of specs
- specification-carrying programs
- in a development environment supporting
  - refinement (top-down)
  - composition (bottom-up)
  - synthesis of verified code
- programming language with
  - guarded commands
  - logical annotations as first-class citizens (available at runtime)
  - procedural abstraction and refinement

What are specs?



spec BinR

spec RefR

spec AsymR

spec TranR

```
spec Poset is
  sort X
  op < : X*X -> Bool

  ax trans is
    x<y /\ y<z => x<z
  ax sym...
end-spec
```

spec BinO

spec Assoc

spec Comm

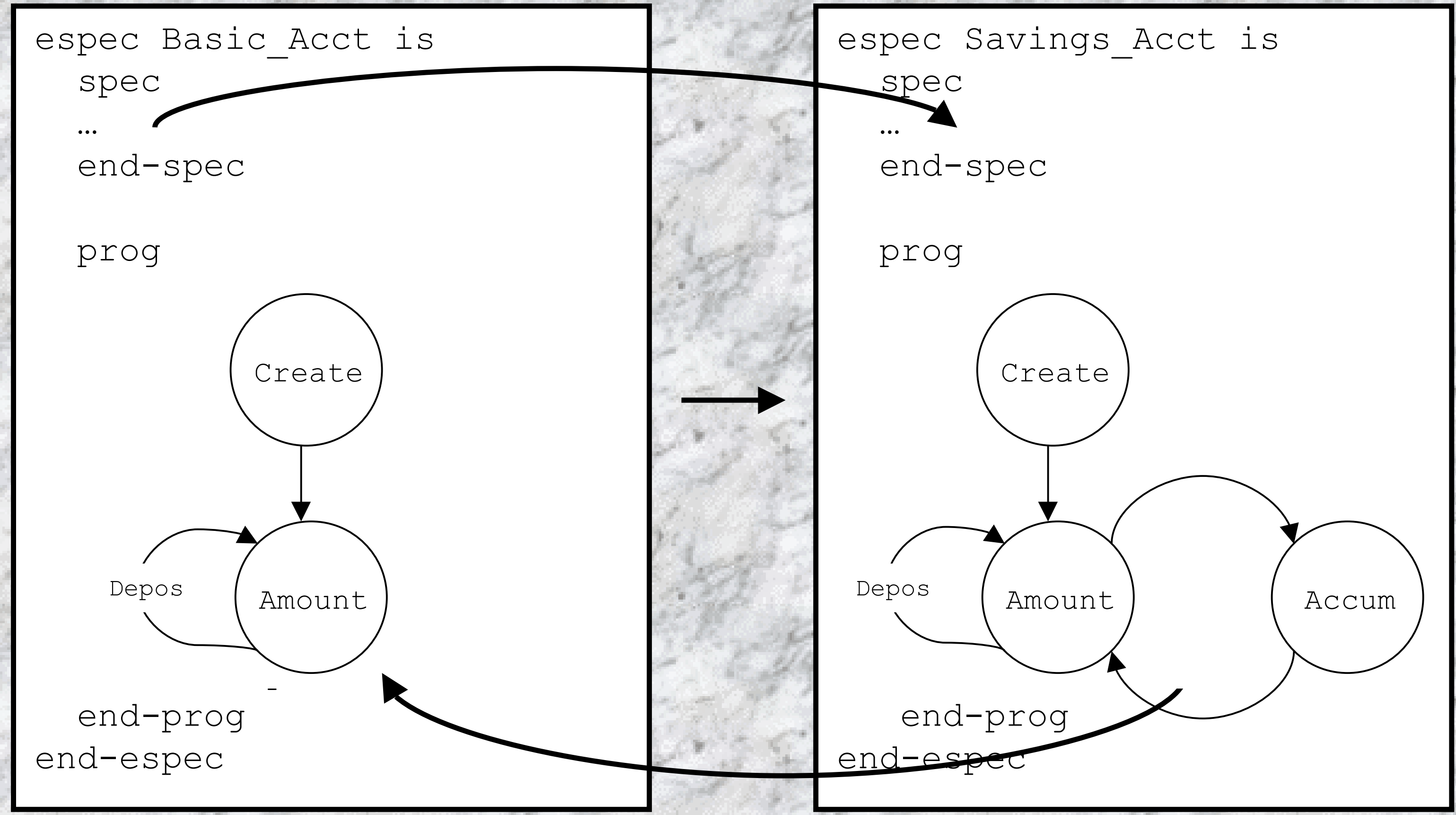
spec Invol

```
spec Semilattice is
  sort X
  op V in : X*X -> X
  cons b : X

  ax assoc is
     (xVy)Vz = xV(yVz)…
end-spec
```

x<y ⟼ xVy=y

What are especs?



```
espec Basic_Acct is
  spec
  …
  end-spec

  prog

  end-prog
end-espec
```

```
espec Savings_Acct is
  spec
  …
  end-spec

  prog

  end-prog
end-espec
```