Principles

1. Increasing volume of measurement operations may not confine the adversary
2. Stronger measurements mimic the dependency chain
   - If a depends on b which depends on c (all at some place p1) then ms(p1,rtm, p1,c) -> ms (p1, c, p1, b) -> ms(p1, b, p1, a) will be the strongest measurement
   - Same idea as *well-supported* measurement from confining paper
   - Hypothesis: if measurement chain is not well-supported, then it is “easy” for an adversary to corrupt

Definition 6. *A measurement event* $e = \mathsf{ms}(o_2, o_1)$ *in execution* E *is* well-supported *iff either*

i. $o_2 = \mathsf{rtm}$, *or*
ii. for every $o \in D^1(o_1)$, *there is a measurement event* $e' \prec_E e$ *such that* o *is the target of* e'.

When e is well-supported, we call the set of e' *from Condition ii above the* support *of* e. *An execution* E measures bottom-up *iff each measurement event* $e \in E$ *is well-supported.*

a
b
c
rtm

Add protocols

- *target: @p4 [ker p4 vc] +~+ @p4 [vc p4 sys]
- *target: @p4 [ker p4 vc] +<+ @p4 [vc p4 sys]

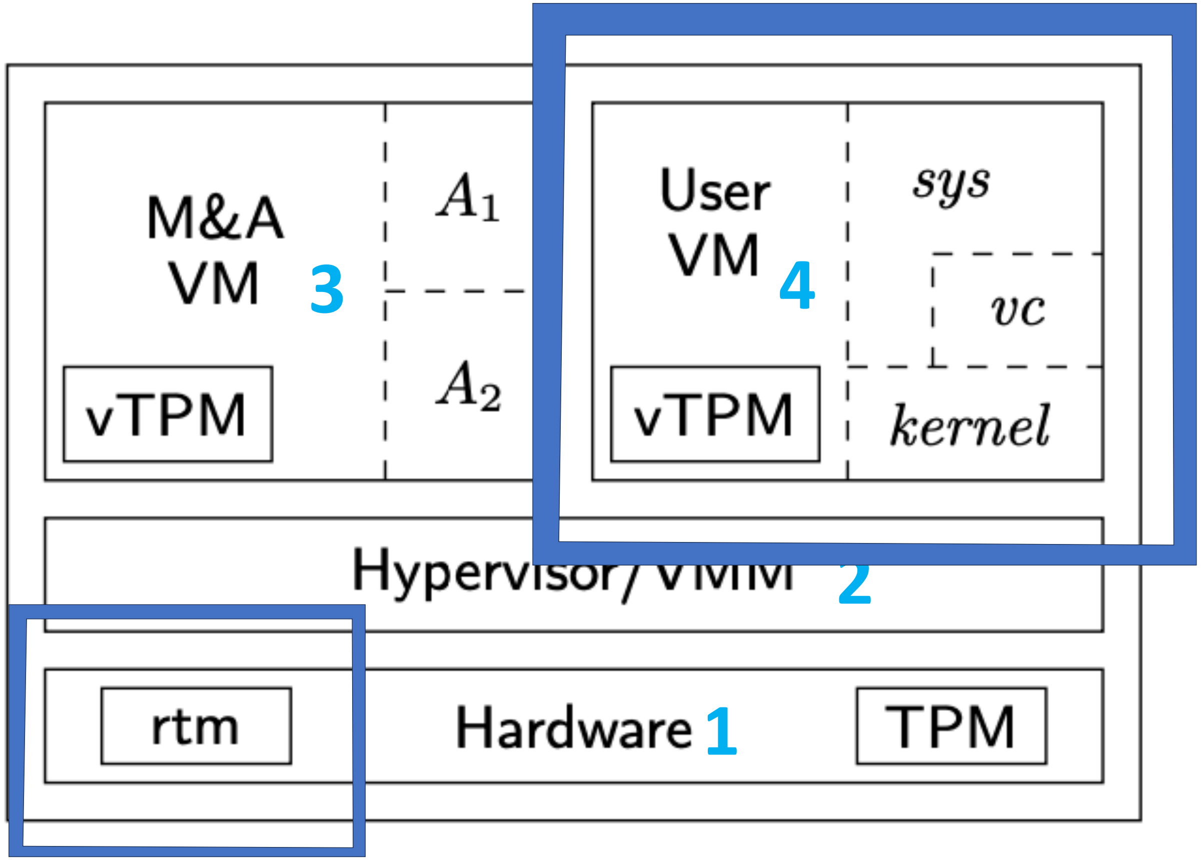
- *target: @p1 [(rtm p4 ker) +~+ @p4 [(ker p4 vc) +~+ @p4 (vc p4 sys)]]
- *target: @p1 [(rtm p4 ker) +<+ @p4 [(ker p4 vc) +<+ @p4 (vc p4 sys)]]

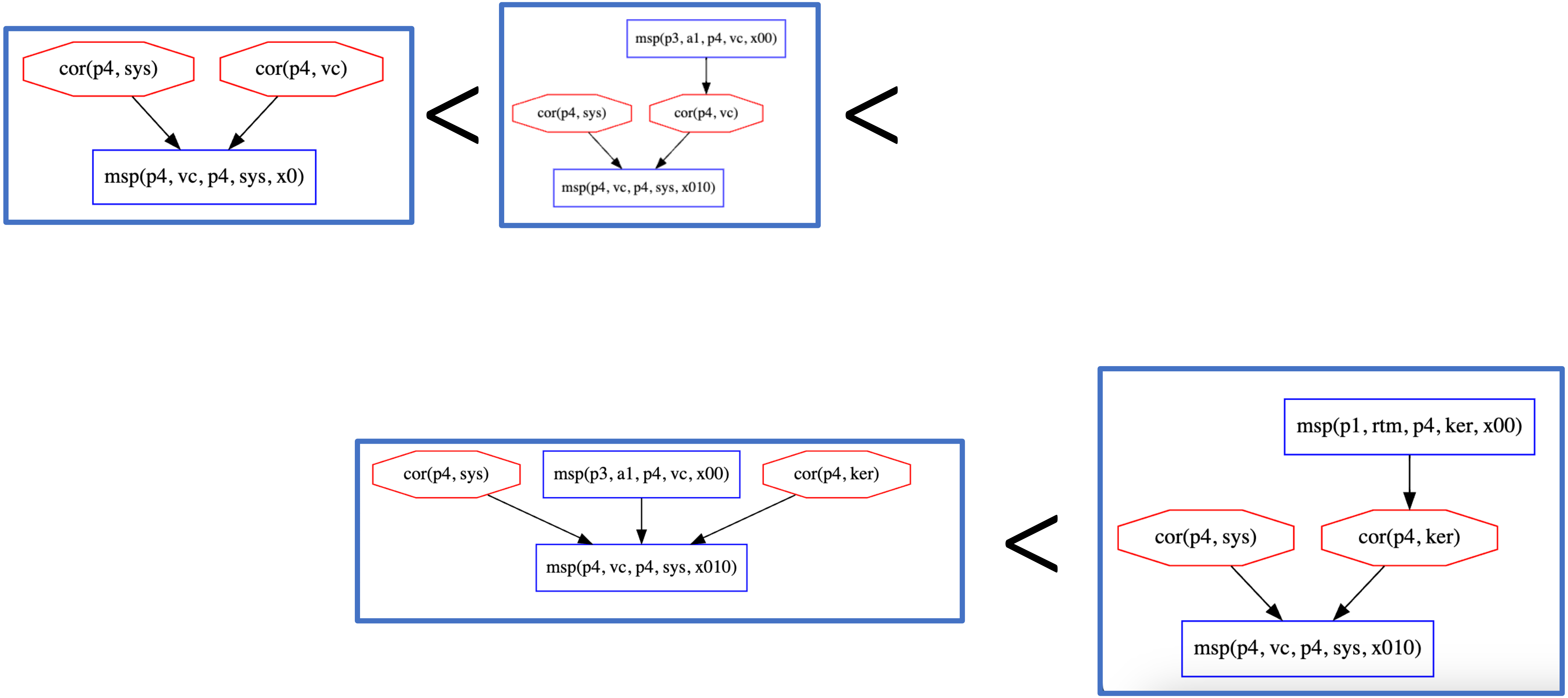
Protocols

Protocol Name	Protocol
sys	*target: @p4 [vc p4 sys]
rtm_ker-sys-par	*target: @p1 [rtm p4 ker +~+ @p4 vc p4 sys]
rtm_ker-sys-seq	*target: @p1 [rtm p4 ker +<+ @p4 vc p4 sys]
ker_vc-sys-par	*target: @p4 [(ker p4 vc) +~+ @p4 (vc p4 sys)]
ker_vc-sys-seq	*target: @p4 [(ker p4 vc) +<+ @p4 (vc p4 sys)]
rtm_ker-vc-sys-par	*target: @p1 [(rtm p4 ker) +~+ @p4 [(ker p4 vc) +~+ @p4 (vc p4 sys)]]
rtm_ker-vc-sys-seq	*target: @p1 [(rtm p4 ker) +<+ @p4 [(ker p4 vc) +<+ @p4 (vc p4 sys)]]
vc-sys-par	*target: @p3 [(a1 p4 vc) +~+ @p4 (vc p4 sys)]
vc-sys-seq	*target: @p3 [(a1 p4 vc) +<+ @p4 (vc p4 sys)]
a1-vc-sys-seq	*target: @p1 [(rtm p3 a1) +<+ @p3 [(a1 p4 vc) +<+ @p4 (vc p4 sys)]]
a1-vc-sys-par	*target: @p1 [(rtm p3 a1) +~+ @p3 [(a1 p4 vc) +~+ @p4 (vc p4 sys)]]
a2-ker-vc-seq	*target: @p1 [rtm p3 a2 +<+ @p3 [a2 p4 ker +<+ @p4 (vc p4 sys)]]
a2-ker-vc-par	*target: @p1 [(rtm p3 a2) +~+ @p3 [(a2 p4 ker) +~+ @p4 (vc p4 sys)]]
a1-a2-vc-ker-sys	*target: @p1 [(rtm p3 a1 +~+ rtm p3 a2) +<+ @p3 [(a1 p4 vc +~+ a2 p4 ker) +<+ @p4 (vc p4 sys1)]]

Say we have the architecture from "Confining the Adversary" Paper

- ms(rtm, A1)
- ms(rtm, A2)
- ms(A1, vc)
- ms(A2, ker)
- msker (vc, sys)




cor(p4, sys)
cor(p4, vc)
msp(p4, vc, p4, sys, x0)
<
msp(p3, a1, p4, vc, x00)
cor(p4, sys)
cor(p4, vc)
msp(p4, vc, p4, sys, x010)
<
cor(p4, sys)
msp(p3, a1, p4, vc, x00)
cor(p4, ker)
msp(p4, vc, p4, sys, x010)
<
msp(p1, rtm, p4, ker, x00)
cor(p4, sys)
cor(p4, ker)
msp(p4, vc, p4, sys, x010)

Corruption event order

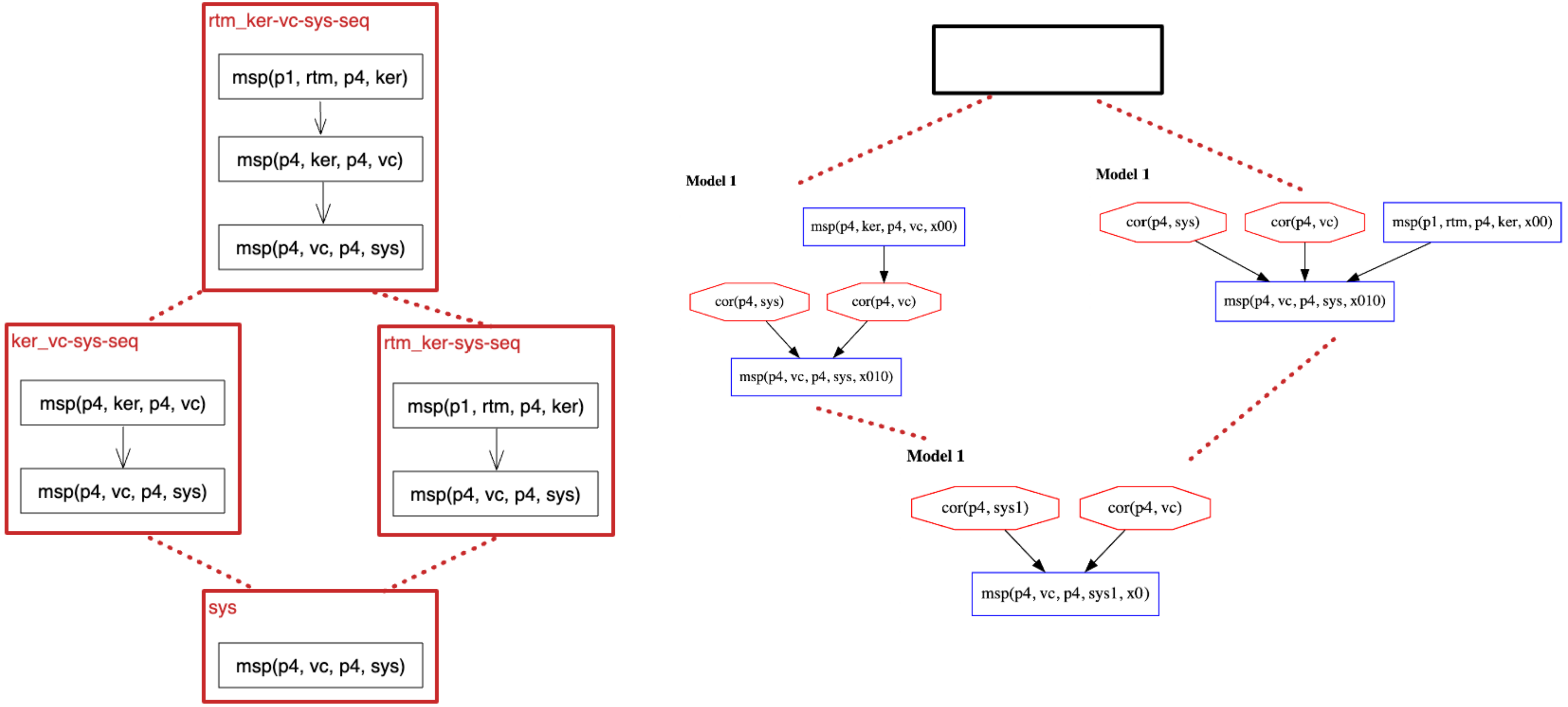
p4 < p1

- To corrupt something at p4 is lowest cost to adversary
- Corrupting at p1 (rtm location) is the highest cost

sys < vc < vc_t < ker < ker_t

- Corrupting the system is easiest for the adversary
- Denote x_t as a corruption event of x in a timely manner

- Possible lattice of protocols



- Ordering relation = subset relation

Old slides (5/16)

Goals of cost analysis

* Maximize the adversary's minimum cost

- Cost considerations
  - Weight of cost depends on component
  - Cor-rep-cor should be more expensive then just corrupt
  - Cost of repair
    - Maybe repair is not costly to an adversary
    - Maybe need to model partial repair (need to decompose system further for this)

What I did for today (5/16)

1. Ran all protocols
2. Selected lowest cost/costs model
3. Took maximum of lowest costs to produce best (?) protocol

Principles

- Increase cost after start event
- Any corruption of a deeper component is higher cost
- Add weight to cost event
    - Have some base cost to the corruption event
    - Add to cost more if its in a protected place

Protocols

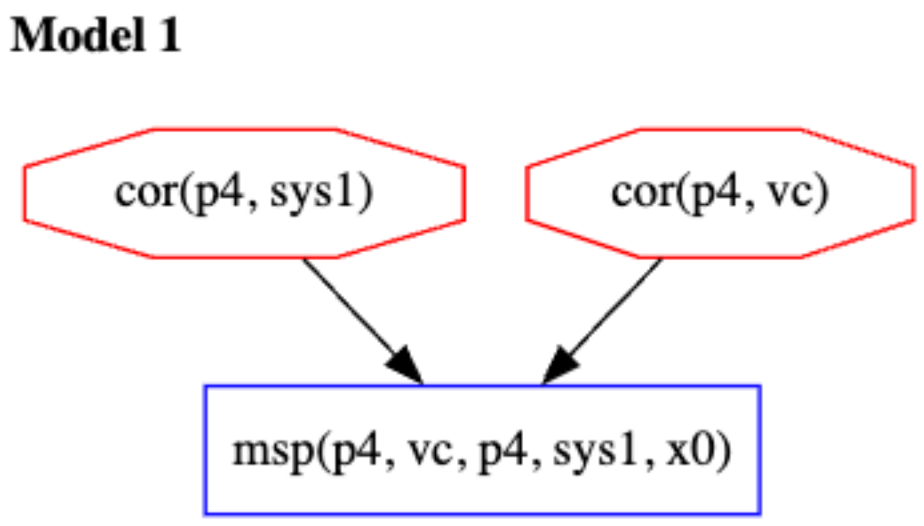
Protocol Name	Protocol
sys	*target: @p4 [vc p4 sys1]
vc-sys-par	*target: @p3 [(a1 p4 vc) +~+ @p4 (vc p4 sys)]
vc-sys-seq	*target: @p3 [(a1 p4 vc) +<+ @p4 (vc p4 sys)]
a1-vc-sys-seq	*target: @p1 [(rtm p3 a1) +<+ @p3 [(a1 p4 vc) +<+ @p4 (vc p4 sys)]]
a1-vc-sys-par	*target: @p1 [(rtm p3 a1) +~+ @p3 [(a1 p4 vc) +~+ @p4 (vc p4 sys)]]
a2-ker-vc-seq	*target: @p1 [rtm p3 a2 +<+ @p3 [a2 p4 ker +<+ @p4 (vc p4 sys)]]
a2-ker-vc-par	*target: @p1 [(rtm p3 a2) +~+ @p3 [(a2 p4 ker) +~+ @p4 (vc p4 sys)]]
a1-a2-vc-ker-sys	*target: @p1 [(rtm p3 a1 +~+ rtm p3 a2) +<+ @p3 [(a1 p4 vc +~+ a2 p4 ker) +<+ @p4 (vc p4 sys1)]]

sys

Protocol: *target: @p4 [vc p4 sys1]

Problem Configuration

```
[ bound = 500, limit = 5000, input_order ]

% Assume adversary avoids detection at our main measurement
% event. This is a measurement of sys
l(V) = msp(p4, M, p4, sys1, X)
 => corrupt_at(p4, sys1, V).

% Assume no dependencies

% No recent assumptions
% prec(V, V1) & l(V1) = cor(P,C) & ms_evt(V)
%  => false.

% No deep assumptions
l(V) = cor(p1, M) => false.

m4_include(`sys.gli')m4_dnl

m4_include(`sys_dist.gli')m4_dnl

m4_include(`thy.gli')m4_dnl
```



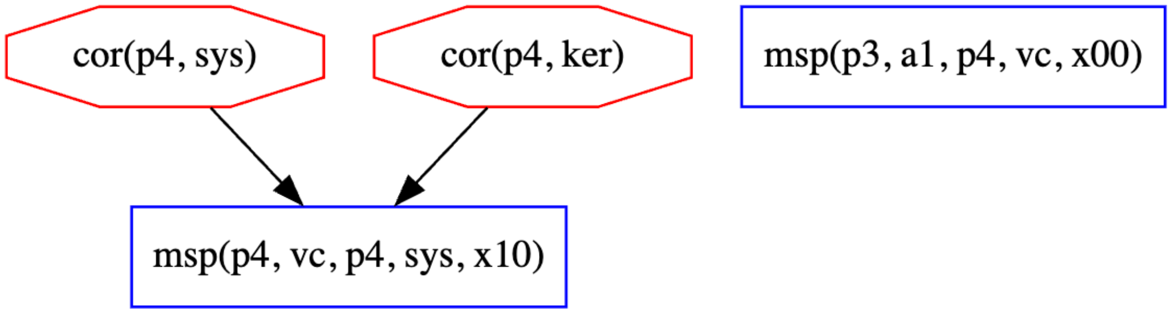
vc-sys-par

- *target: @p3 [(a1 p4 vc) +~+ @p4 (vc p4 sys)]

Problem Configuration

```
[ bound = 500, limit = 5000, input_order ]

% Assume adversary avoids detection at
% our main measurement event.
% This is a measurement of sys.
l(V) = msp(p4, M, p4, sys, X)
 => corrupt_at(p4, sys, V).

% Assume dependencies
depends(p4, C, p4, sys) => C = ker.
depends(p4, C, p4, vc) => C = ker.
% rtm has no dependencies
depends(p1, C, p1, rtm) => false.

% Assume no recent corruptions
%prec(V, V1) & l(V1) = cor(P,C) & ms_evt(V)
%=> false.

% Assume no deep corruptions
l(V) = cor(p1, M) => false.

m4_include(`vc-sys-par.gli')m4_dnl

m4_include(`vc-sys-par_dist.gli')m4_dnl

m4_include(`thy.gli')m4_dnl
```

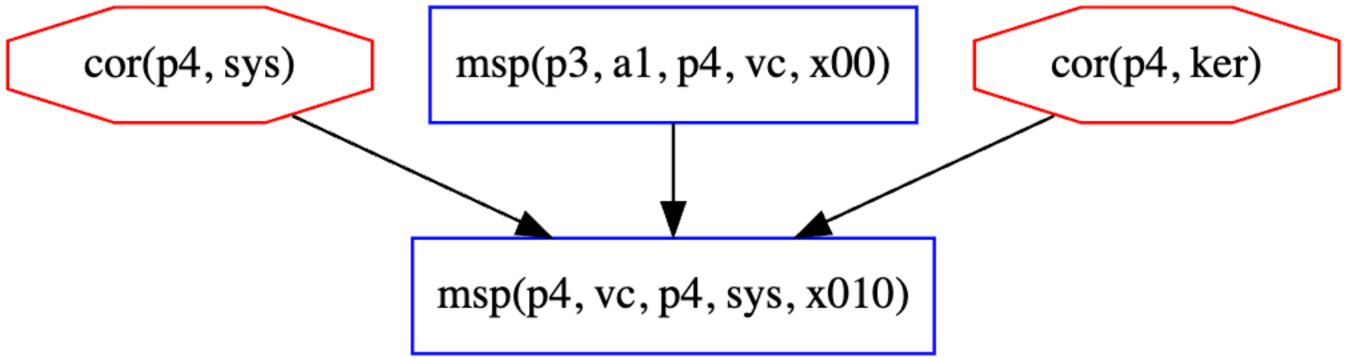
Model 2



vc-sys-seq

- *target: @p3 [(a1 p4 vc) +<+ @p4 (vc p4 sys)]

Model 2



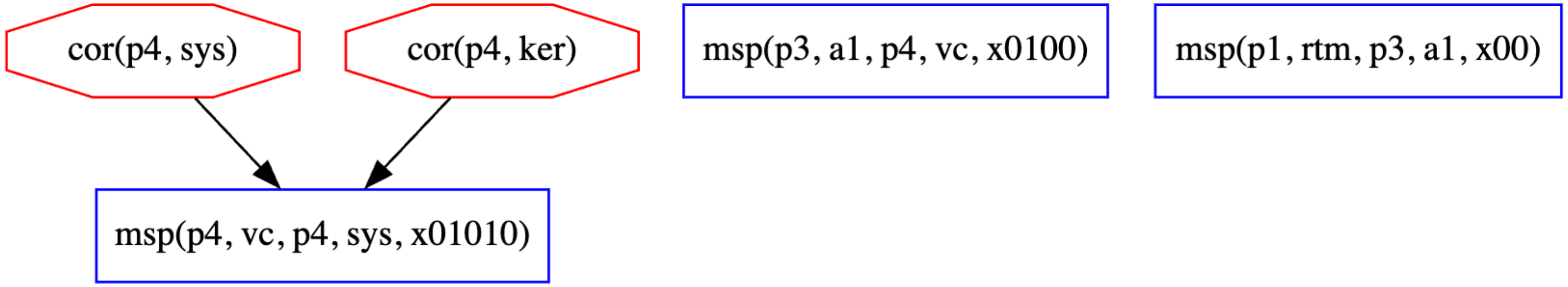
a1-vc-sys-par

Protocol:

*target: @p1 [(rtm p3 a1) +~+ @p3 [(a1 p4 vc) +~+ @p4 (vc p4 sys)]]

```
% Assume adversary avoids detection at
% our main measurement event.
% This is a measurement of sys.
l(V) = msp(p4, M, p4, sys, X)
 => corrupt_at(p4, sys, V).

% system dependencies
depends(p4, C, p4, sys) => C = ker.
depends(p4, C, p4, vc) => C = ker.

% rtm has no dependencies
depends(p1, C, p1, rtm) => false.


% Assume no recent corruptions
% prec(V, V1) & l(V1) = cor(P,C) & ms_evt(V)
% => false.

% Assume no deep corruptions
l(V) = cor(p1, M) => false.
```

Model 2

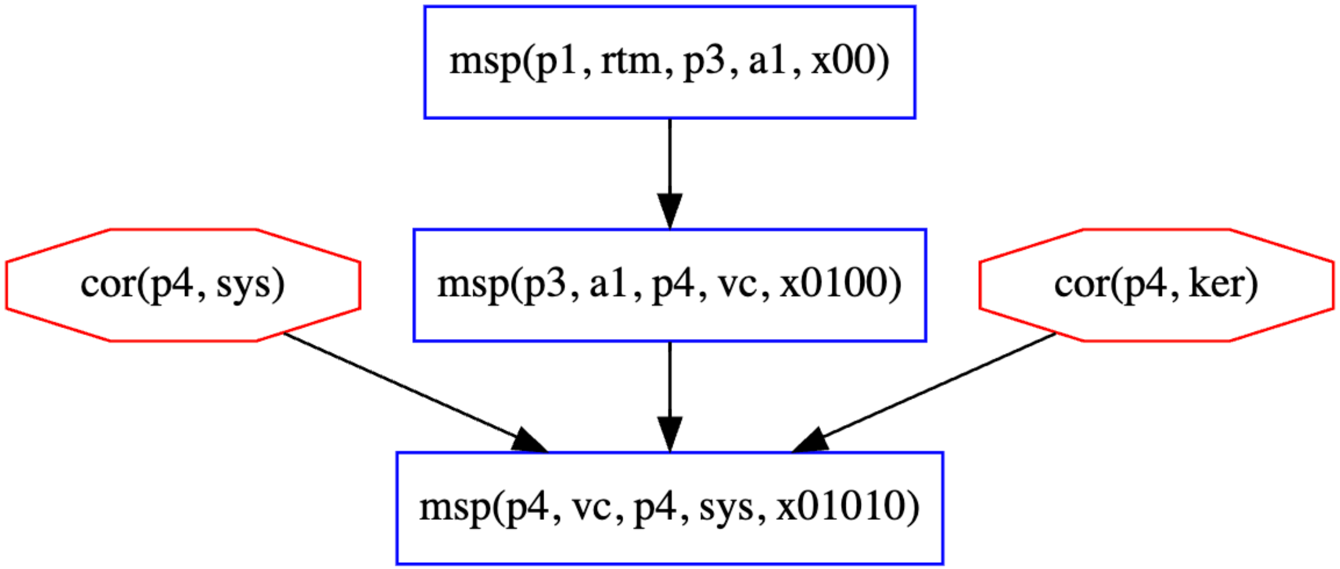


A1-vc-sys-seq

Protocol:

*target: @p1 [(rtm p3 a1) +<+ @p3 [(a1 p4 vc) +<+ @p4 (vc p4 sys)]]

Model 2



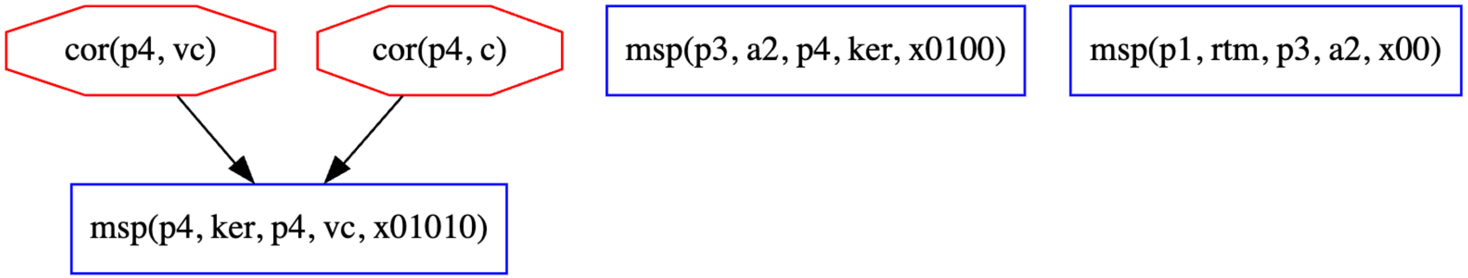
a2-ker-vc-par

- *target: @p1 [(rtm p3 a2) +~+ @p3 [(a2 p4 ker) +~+ @p4 (ker p4 vc)]]

Problem Configuration

```
[ bound = 500, limit = 5000, input_order ]

% Assume adversary avoids detection at
% our main measurement event.
% This is a measurement of ker.
l(V) = msp(p4, M, p4, vc, X)
 => corrupt_at(p4, vc, V).

% dependencies
depends(p4, C, p4, sys) => C = ker.
depends(p4, C, p4, vc) => C = ker.
% rtm has no dependencies
depends(p1, C, p1, rtm) => false.


% Assume no recent corruptions
%prec(V, V1) & l(V1) = cor(P,C) & ms_evt(V)
%  => false.

% Assume no deep corruptions
l(V) = cor(p1, M) => false.

m4_include(`a2-ker-vc-par.gli')m4_dnl

m4_include(`a2-ker-vc-par_dist.gli')m4_dnl

m4_include(`thy.gli')m4_dnl
```

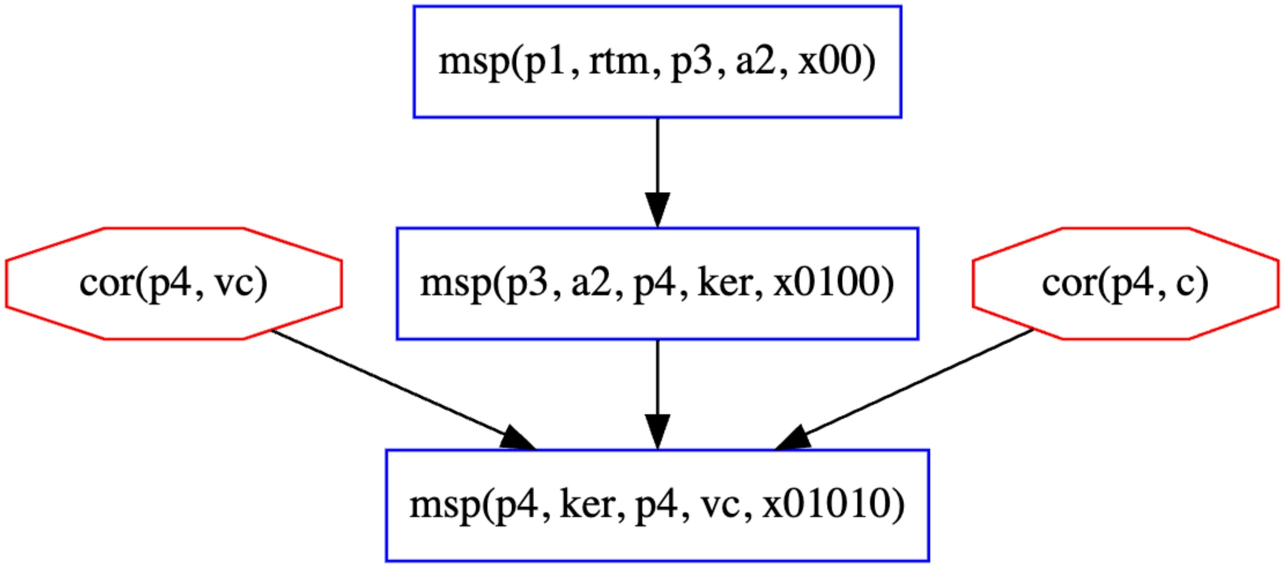
Model 1



a2-ker-vc-seq

- *target: @p1 [rtm p3 a2 +<+ @p3 [a2 p4 ker +<+ @p4 (ker p4 vc)]]

Model 1

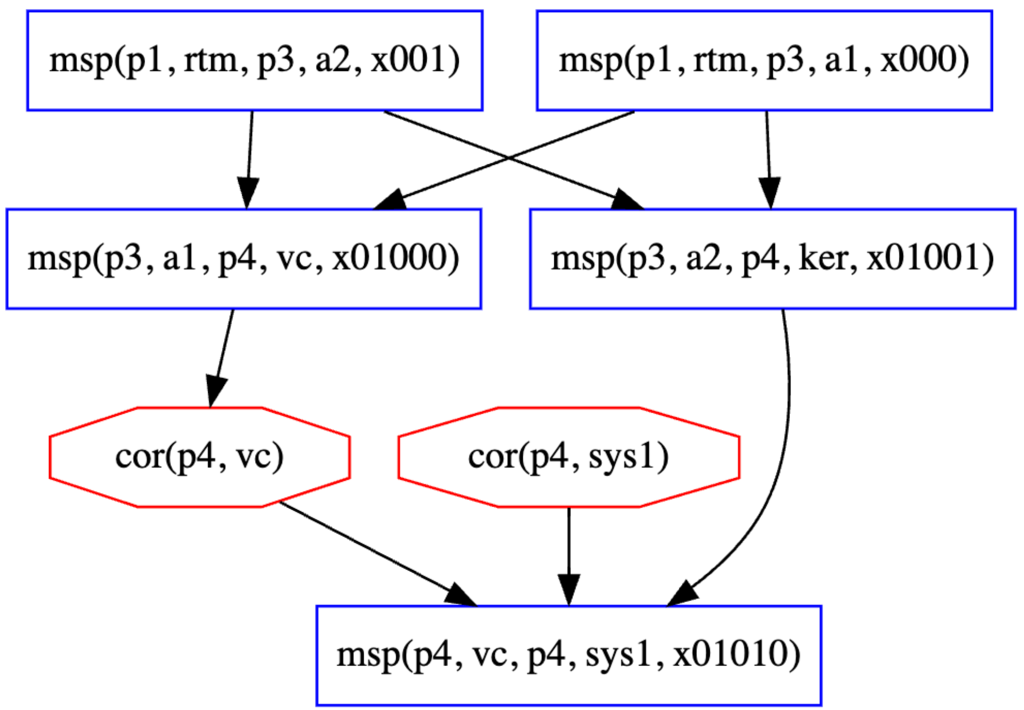


a1-a2-vc-ker-sys

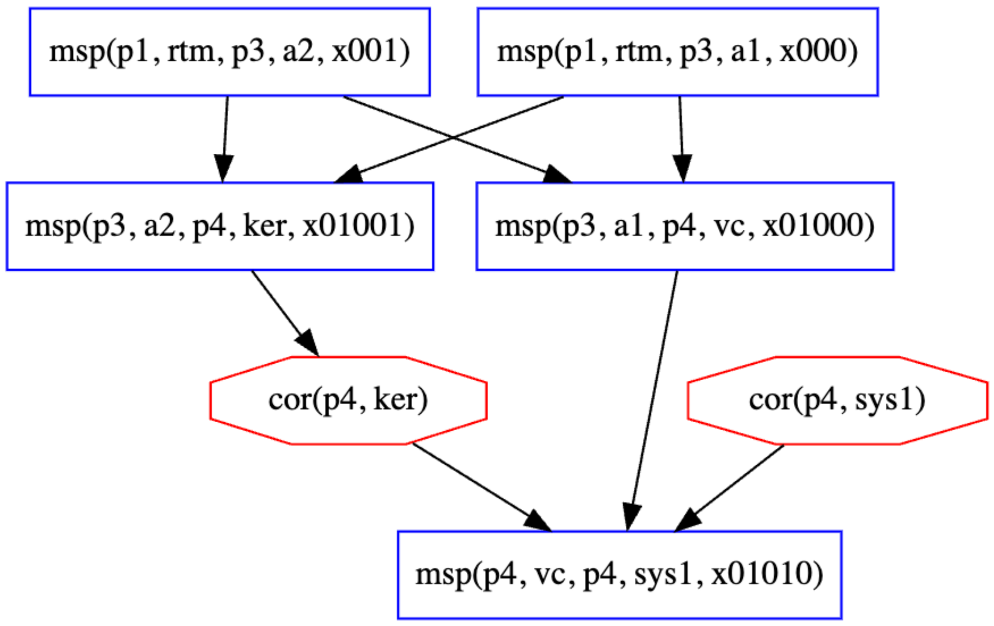
- *target: @p1 [(rtm p3 a1 +~+ rtm p3 a2) +<+ @p3 [(a1 p4 vc +~+ a2 p4 ker) +<+ @p4 (vc p4 sys1)]]

```
% dependencies
depends(p4, C, p4, sys1) => C = ker.
depends(p4, C, p4, vc) => C = ker.
% depends(p1, C, p4, ker) => C = rtm.
% depends(p1, C, p3, a1) => C = rtm.

% depends(P1, C, p3, a2) => P1 = p1 & C = rtm.
% rtm has no dependencies
depends(p1, C, p1, rtm) => false.


% Assume no recent corruptions
%prec(V, V1) & l(V1) = cor(P,C) & ms_evt(V)
%  => false.

% Assume no deep corruptions
l(V) = cor(p1, M) => false.
```

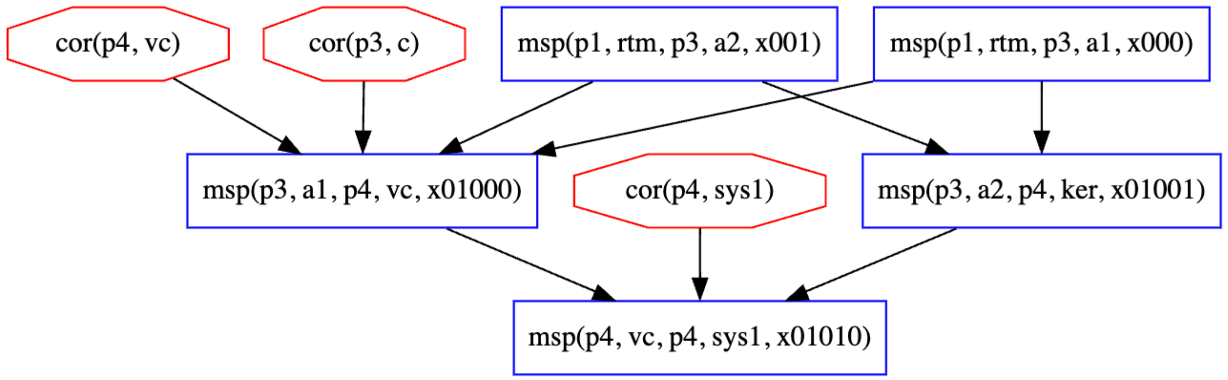
Model 1



Model 2



Model 4



Same protocol… change theory

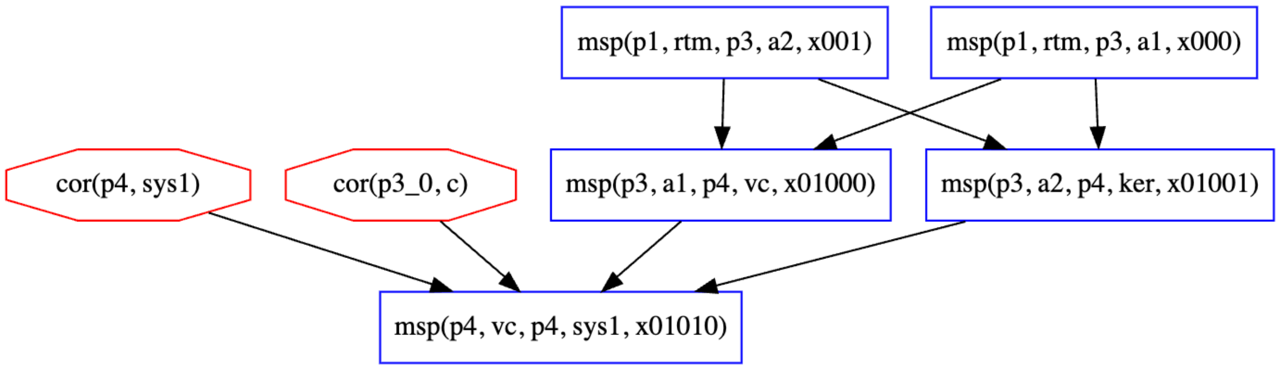
Problem Configuration

```
[ bound = 500, limit = 5000, input_order ]

% Assume adversary avoids detection at
% our main measurement event.
% This is a measurement of ker.
l(V) = msp(p4, M, p4, sys1, X)
 => corrupt_at(p4, sys1, V).

% dependencies
depends(p4, C, p4, sys1) => C = ker.
depends(p4, C, p4, vc) => C = ker.
depends(P1, C, p4, ker) => P1 = p1 & C = rtm.
depends(P1, C, p3, a1) => P1 = p1 & C = rtm.
depends(P1, C, p3, a2) => P1 = p1 & C = rtm.
% rtm has no dependencies
depends(p1, C, p1, rtm) => false.


% Assume no recent corruptions
%prec(V, V1) & l(V1) = cor(P,C) & ms_evt(V)
%  => false.

% Assume no deep corruptions
l(V) = cor(p1, M) => false.

m4_include(`a1-a2-vc-ker-sys.gli')m4_dnl

m4_include(`a1-a2-vc-ker-sys_dist.gli')m4_dnl

m4_include(`thy.gli')m4_dnl
```

```
% Rule 1
%l(V) = msp(P2, M, P1, T, X) & corrupt_at(P1, T, V)
%  => corrupt_at(P2, M, V) | depends(P2, C, P2, M) & corrupt_at(P2, C, V).
%corruption events can be at different places
l(V) = msp(P2, M, P1, T, X) & corrupt_at(P1, T, V)
  => corrupt_at(P2, M, V) | depends(P3, C, P2, M) & corrupt_at(P3, C, V).
```

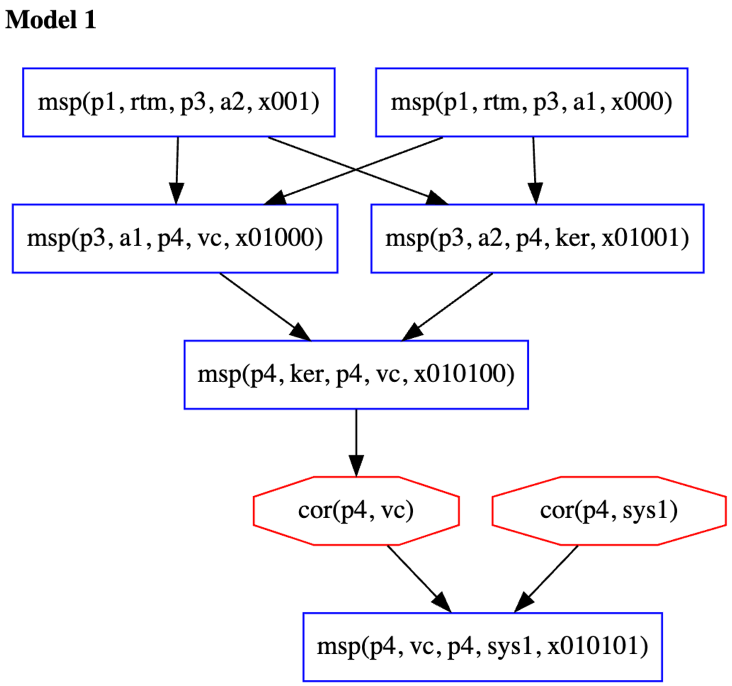
Models

Model 1



Back to original theory… change measurement

- *target: @p1 [(rtm p3 a1 +~+ rtm p3 a2) +<+
  @p3 [(a1 p4 vc +~+ a2 p4 ker) +<+
  @p4 [(ker p4 vc) +<+ (vc p4 sys1)]]]



Ways to manipulate CHASE outcome

Things I tried but didn't have much impact…

1. Change measurement combination (parallel to sequence)
2. Add measurements
   - Not sure how to distinguish when something is a "useful" measurement
3. Changing dependencies

Additional Slides (5/5)

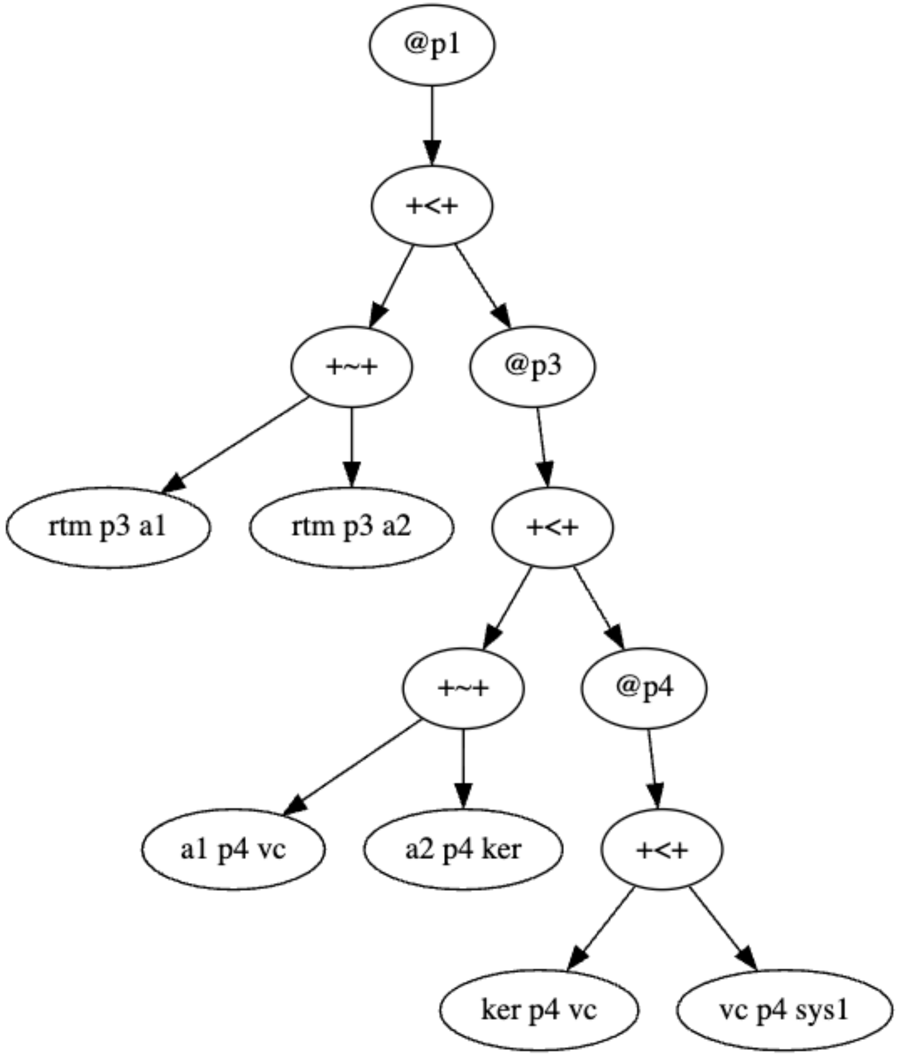
Or previously run protocols…

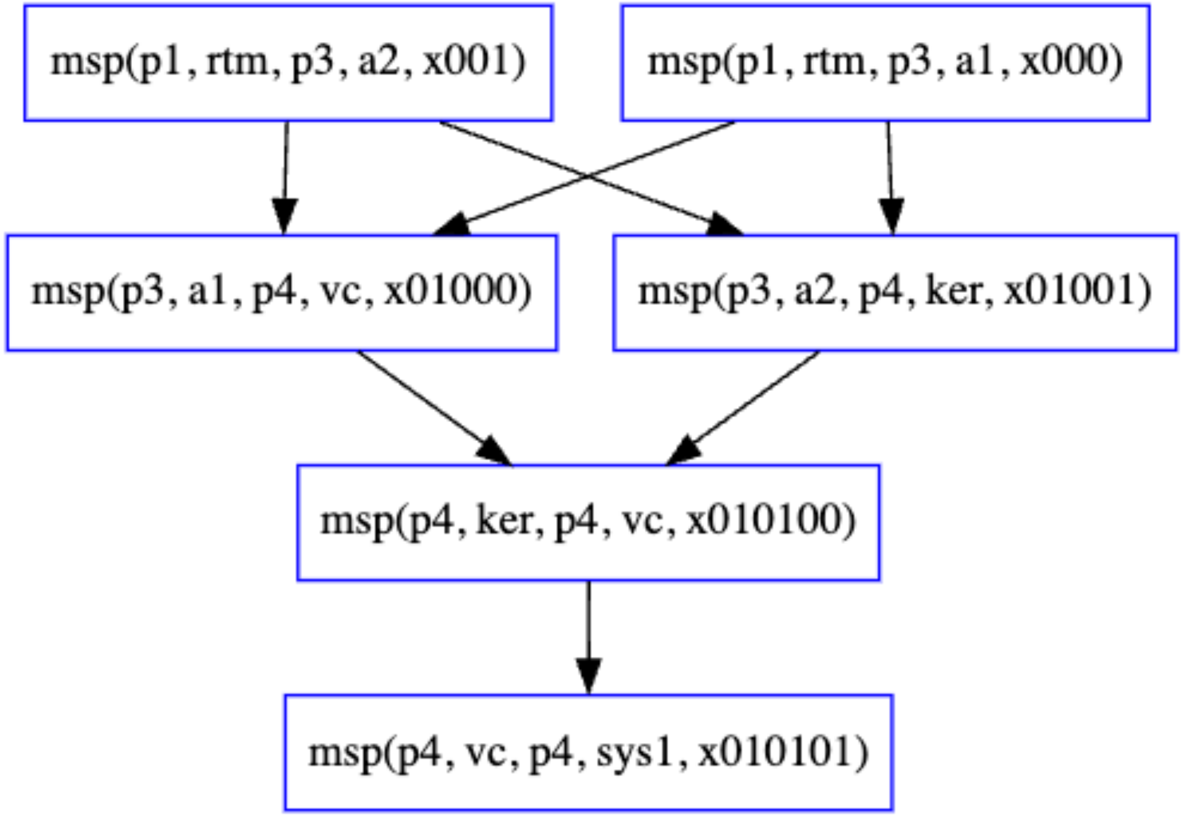
Assumptions

- Always assume deep theorem (remove recent theorem)
  - l(V) = cor(p1, M) => false.
- Assumptions about system dependencies
  - TPM is the root of trust… has no dependencies
  - Virus checker depends on kernel (p4,ker)
  - System depends on kernel (p4,ker)
  - Kernel depends on the hardware (p1,rtm)
  - A1 depends on the hardware (p1,rtm)
  - A2 depends on the hardware (p1,rtm)

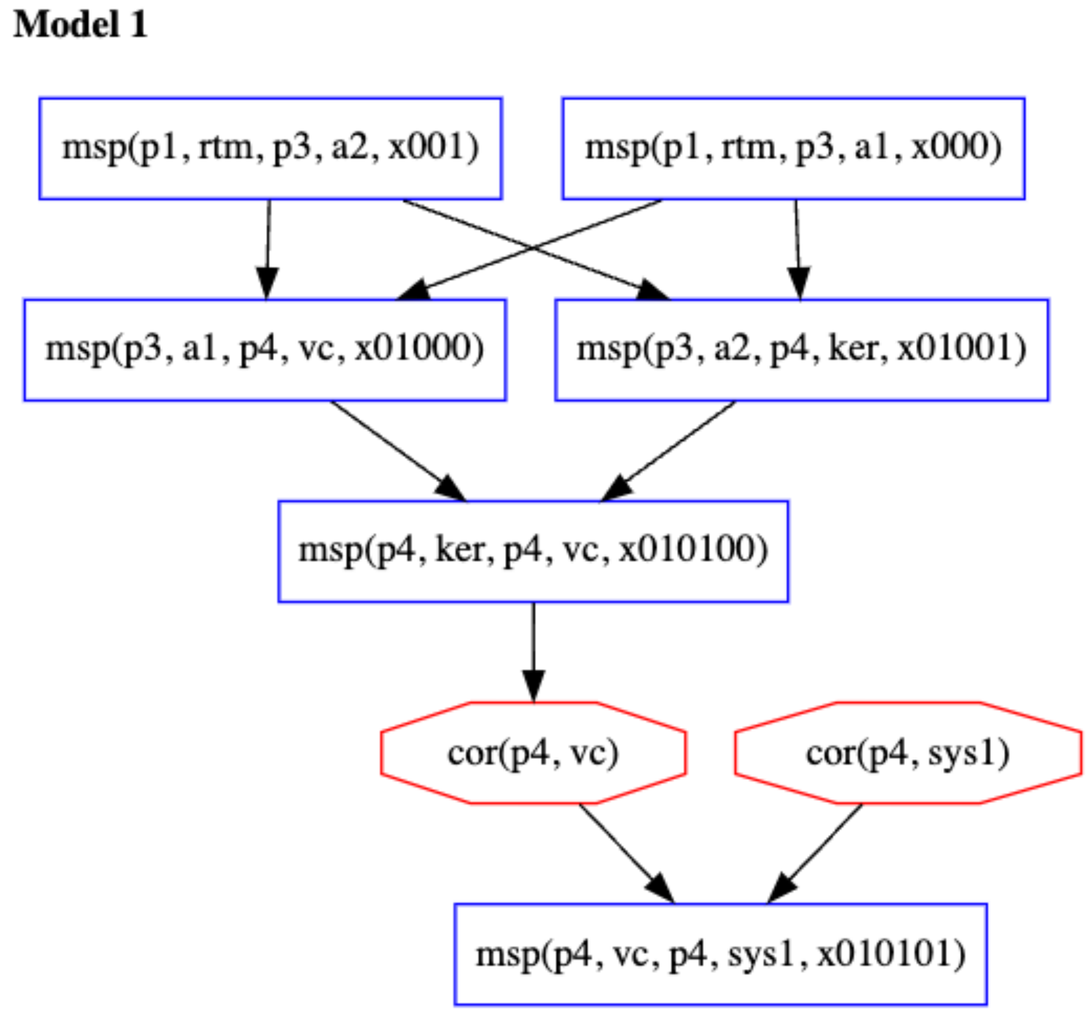
```
% dependencies
depends(p4, C, p4, sys1) => C = ker.
depends(p4, C, p4, vc) => C = ker.
depends(p1, C, p4, ker) => C = rtm.
depends(p1, C, p3, a1) => C = rtm.
depends(p1, C, p3, a2) => C = rtm.
% rtm has no dependencies
depends(p1, C, p1, rtm) => false.
```

Abstract Syntax Tree

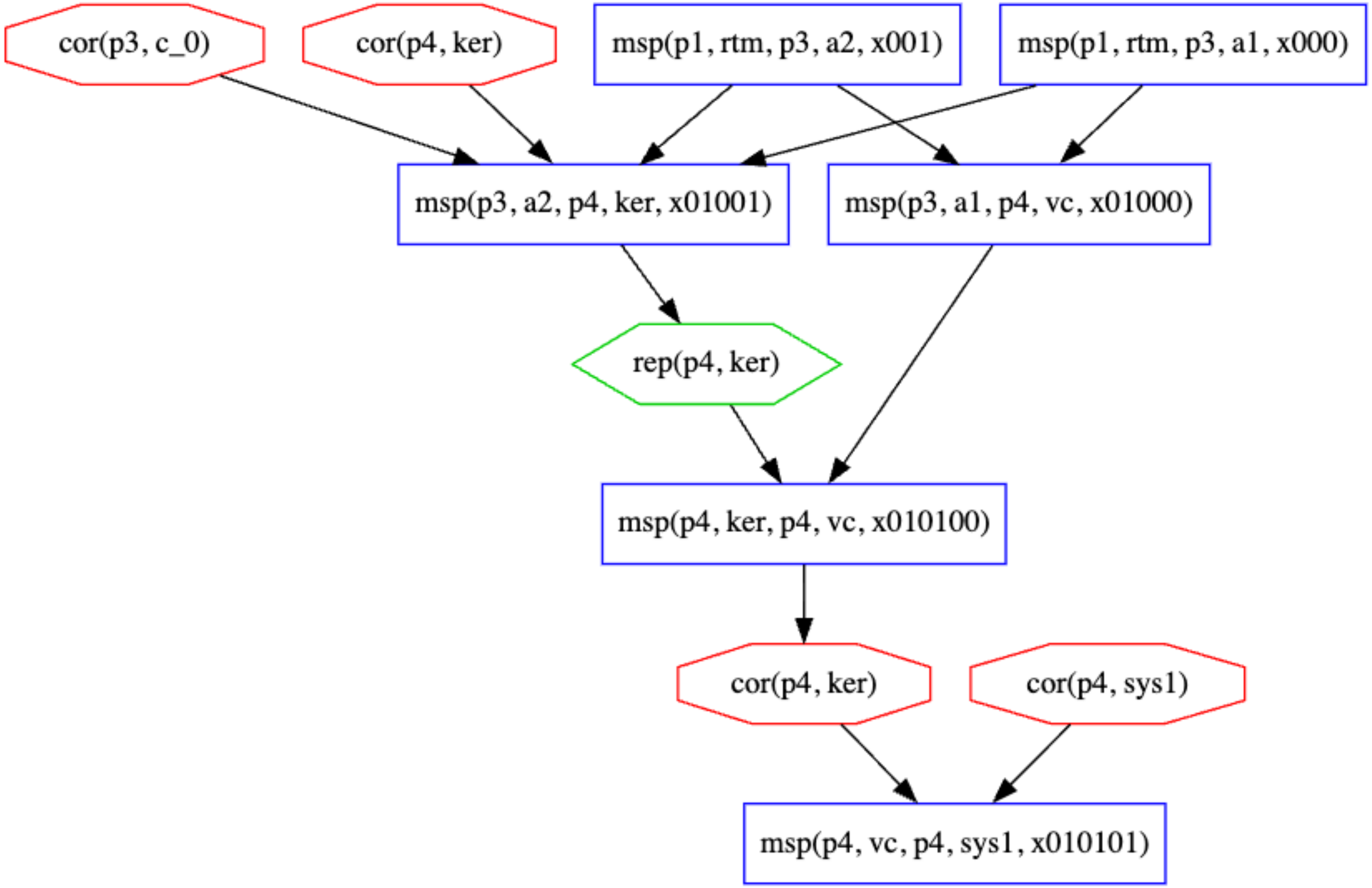




Assuming recent measurements may be corrupted there are 21 models…



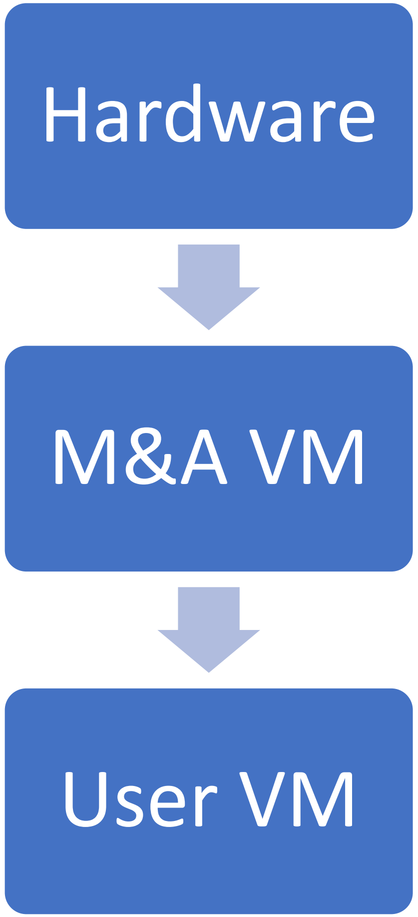
Model 21


cor(p3, c_0)
cor(p4, ker)
msp(p1, rtm, p3, a2, x001)
msp(p1, rtm, p3, a1, x000)
msp(p3, a2, p4, ker, x01001)
msp(p3, a1, p4, vc, x01000)
rep(p4, ker)
msp(p4, ker, p4, vc, x010100)
cor(p4, ker)
cor(p4, sys1)
msp(p4, vc, p4, sys1, x010101)

Order	Event	Cost	Present In	Details
low	cor(p4,sys1)	c1	all models	Always before the last measurement event
	cor(p4,c)	c2	4	happens before ms(ker,vc)
	cor(p4,vc)	c3	1 4 5 8 9 10 11 12 13 14 15 16 17 18(2) 19(2)	occurs after some attestation start event (between measurements) or before a measurement, sometimes happens twice (once and then after a repair)
	cor(p4, ker)	c4	2 3 5 6 7 10 11 12 13 14 15 16 17 20(2) 21(2)	occurs various places.. Before/after ms(a2,ker), before ms(vc,sys1)
	cor(p4,c_1)	c5	8	before ms(ker,vc)
	cor(p3,a1)	c6	8 10 14 15 18	before ms(a1,vc), always after the attestation begins… maybe this is most difficult because you have to consider time window for adversary
	cor(p3,c_3)	c7	9 11 16 17 19	before ms(a1,vc), no attestation start event… could be easiest for an adversary
	cor(p4,c_2)	c8	9	before ms(ker,vc), no attestation start event… could be easiest for adversary
	cor(p3,a2)	c9	6 12 14 16 20	between ms(rtm, a2) – ms(a2, ker)… close to root of trust. Difficult for an adversary
	cor(p3,c_4)	c10	13	before ms(a2,ker), no attestation start event… could be easiest for adversary
	cor(p3,c_5)	c11	15	before ms(a2,ker) no attestation start event… could be easiest for adversary
	cor(p3,c_6)	c12	17	before ms(a2,ker) , no attestation start event… could be easiest for adversary
	rep(p4,vc)	c13	18 19	between ms(a1,vc) – ms(ker,vc),
	rep(p4,ker)	c14	20 21	between ms(a2,ker) -- ms(ker, vc)
	cor(p3,c_0)	c15	7 21	before ms(a2,ker)

Considering Cost to an Adversary

- Hardware = highest cost to adversary
- M&A = middle cost
- User VM = lowest cost to an adversary



Considering Cost to an Attester

- Hardware = worst case for an adversary
- M&A = ??
- User VM =??

Cost

Cost	Reasoning
high	• corruption events that occur between measurement events are difficult… Thus, high cost • corruption events closer to root of trust are difficult. Thus, high cost. • corruption then repair then corruption requires a lot of work from adversary. This is a high cost.
medium	• corruption event at M&A domain is medium as it is in the middle of the architecture
low	• corruption before last measurement is probably the easiest thing for an adversary therefore the lowest cost.

Thoughts/Takeaways

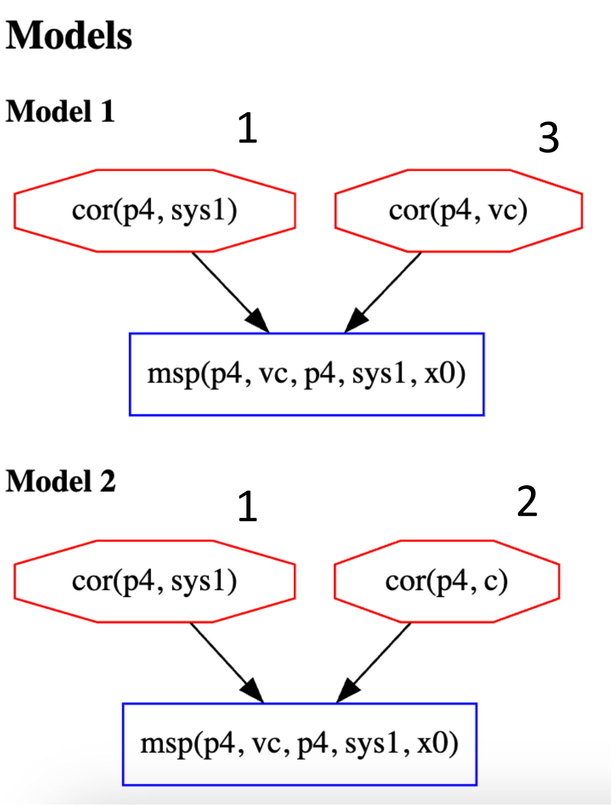
- Write some script to assign cost

Additional Slides

Or previously run protocols…

sys

First protocol…. Just measure *sys* using *vc*



Event	Cost
cor(p4,sys1)	c1
cor(p4,vc)	c3
cor(p4,c)	c2
MODEL 1 COST	c1 + c3
MODEL 2 COST	c1 + c2

If you add in dependencies about a then labels to corruption events change

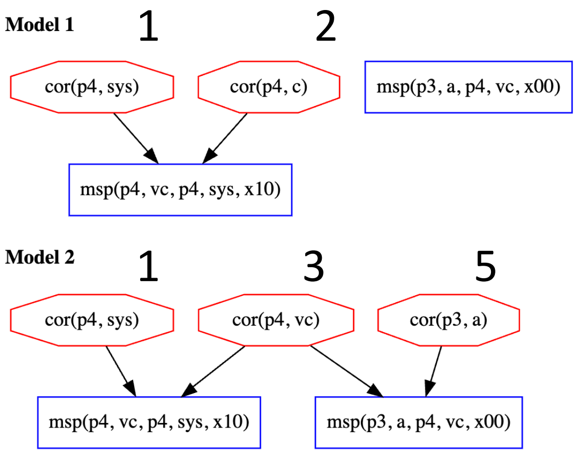
Measure *vc* and *sys* in parallel

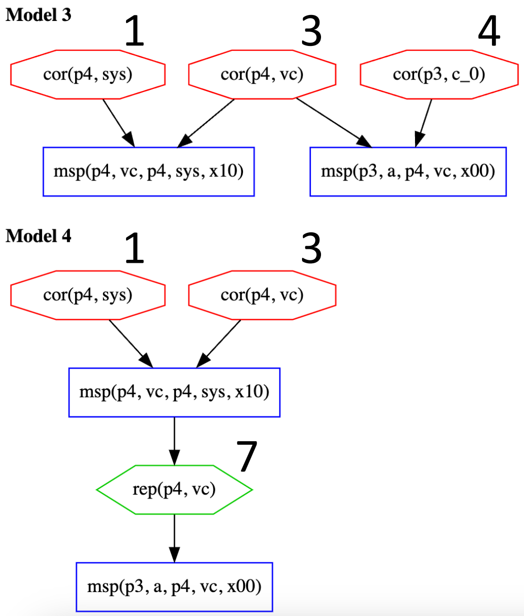
- Protocol
  - *target: @p3 [a p4 vc]

    +~+ @p4 [vc p4 sys]

```
% Assume dependencies
% if sys1 or vc depend on anything, that thing is the root of trust
depends(p1, C, p4, sys) => C = rtm.
depends(p1, C, p4, vc) => C = rtm.
depends(p1, C, p3, a) => C = rtm.
% rtm has no dependencies
depends(p1, C, p1, rtm) => false.

% Assume no recent corruptions
prec(V, V1) & l(V1) = cor(P,C) & ms_evt(V)
=> false.

% Assume no deep corruptions
l(V) = cor(p1, M) => false.
```

Models





Model	Total cost
1	c1 + c2
2	c1 + c3 + c5
3	c1 + c3 + c4
4	c1 + c3 + c7

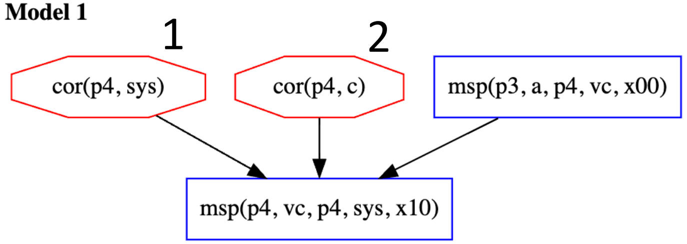
Measure *vc* and *sys* in sequence

- Protocol
  - *target: @p3 [a p4 vc]
    +<+ @p4 [vc p4 sys]

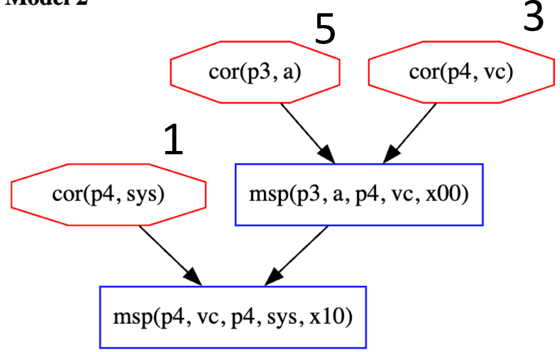
Model	Total cost
1	c1 + c2
2	c1 + c3 + c4
3	c1 + c5 + c3

Models

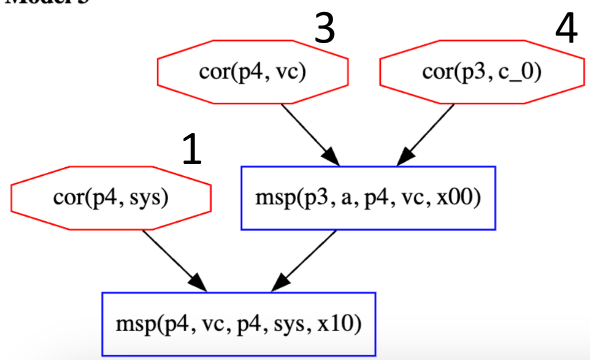
Model 1



Model 2



Model 3

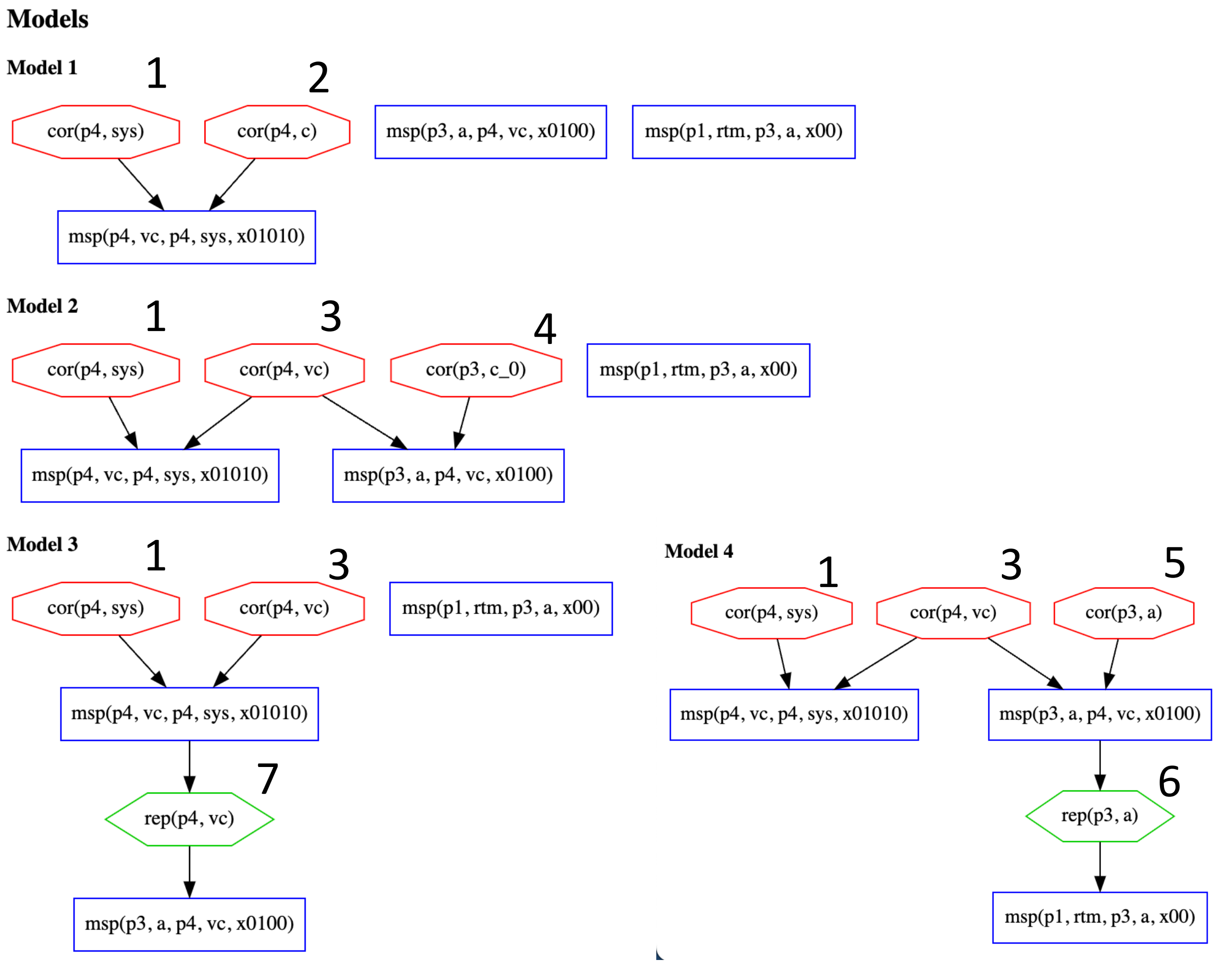


If you add deep thm about p3 model 2 and 3 are removed a-vc-sys-par

Measure *a* then *vc* then *sys* in parallel

- Protocol
  - *target: @p1 [rtm p3 *a*
    +~+ @p3 [a p4 *vc*
    +~+ @p4 [vc p4 *sys*]]]]

Model	Total cost
1	c1 + c2
2	c1 + c2 + c4
3	c1 + c3 + c7
4	c1 + c3 + c5 + c6

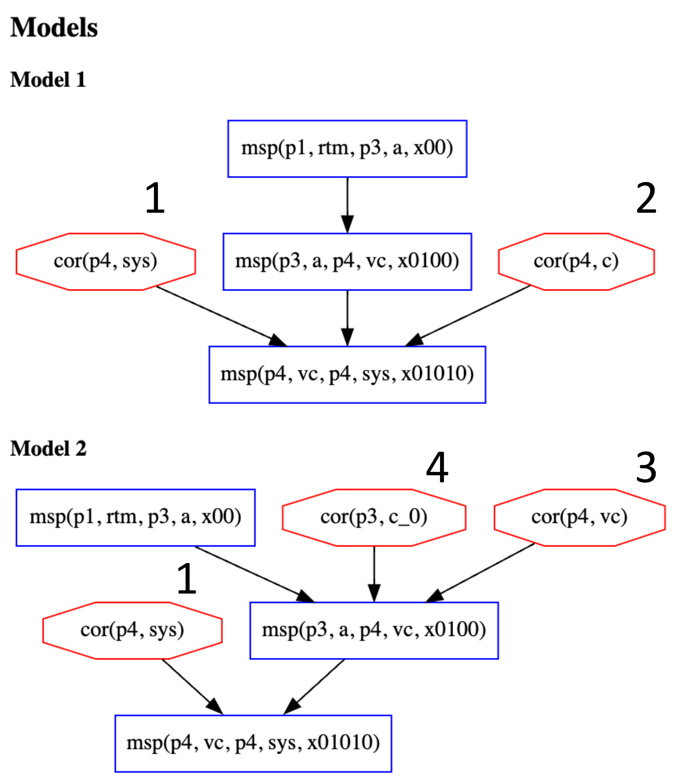


a-vc-sys-seq

Measure *a* then *vc* then *sys* in sequence

- Protocol
  - *target: @p1 [rtm p3 *a*
    +<+ @p3 [a p4 *vc*
    +<+ @p4 [vc p4 *sys*]]]]

Model	Total cost
1	c1 + c2
2	c1 + c3 + c4



All together

label	protocol	total cost
sys	*target: @p4 [vc p4 sys1]	(c1 + c3) OR (c1 + c2)
vc-sys-par	*target: @p3 [a p4 vc] +~+ @p4 [vc p4 sys]	(c1 + c2) OR (c1 + c3 + c5) OR (c1 + c3 + c4) OR (c1 + c3 + c7)
vc-sys-seq	*target: @p3 [a p4 vc] +<+ @p4 [vc p4 sys]	(c1 + c2) OR (c1 + c3 + c4) OR (c1 + c5 + c3)
a-vc-sys-par	*target: @p1 [rtm p3 *a* +~+ @p3 [a p4 *vc* +~+ @p4 [vc p4 *sys*]]]]	(c1 + c2) OR (c1 + c2 + c4) OR (c1 + c3 + c7) OR (c1 + c3 + c5 + c6)
a-vc-sys-seq	*target: @p1 [rtm p3 *a* +<+ @p3 [a p4 *vc* +<+ @p4 [vc p4 *sys*]]]]	(c1 + c2) OR (c1 + c3 + c4)

Event with label and cost

Event	Label	Cost	Present In
cor(p4,sys)	1	c1	sys(1,2),vc-sys-par(1,2,3,4), vc-sys-seq(1,2,3), a-vc-sys-par(1,2,3,4), a-vc-sys-seq(1,2)
cor(p4,c)	2	c2	sys(2), vc-sys-par(2), vc-sys-seq(1), a-vc-sys-par(1,2), a-vc-sys-seq(1)
cor(p4,vc)	3	c3	sys(1), vc-sys-par(2,3,4), vc-sys-seq(2,3), a-vc-sys-par(3,4), a-vc-sys-seq(2)
cor(p3, c_0)	4	c4	vc-sys-par(3), vc-sys-seq(2), a-vc-sys-par(2), a-vc-sys-seq(2)
cor(p3,a)	5	c5	vc-sys-par(2), vc-sys-seq(3), a-vc-sys-par(4)
rep(p3,a)	6	c6	a-vc-sys-par(4)
rep(p4,vc)	7	c7	vc-sys-par(4), a-vc-sys-par(3)

Control Variables

```
% Assume sys depends on kernel
% if sys1 or vc depend on anything, that thing is the root of trust
depends(p1, C, p4, sys) => C = rtm.
depends(p1, C, p4, vc) => C = rtm.
depends(p1, C, p3, a) => C = rtm.
% rtm has no dependencies
depends(p1, C, p1, rtm) => false.

% Assume no deep corruptions
l(V) = cor(p1, M) => false.
```

- Assumptions
    - Always assume recent/deep
    - Make no assumptions about system dependencies except…
        - TPM is the root of trust… has no dependencies
        - Virus checker and system depend on the hardware (p1,rtm)
        - A1 depends on the hardware (p1,rtm)

Side note: I changed all theory files to the original… allows for corruption only at the same place

- If I made it allow for corruption at different places… CHASE seemed to introduce corruption events with odd labels