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LOCAL STATES

More hidden states, more modalities, and generalized invariants and ghost ownership

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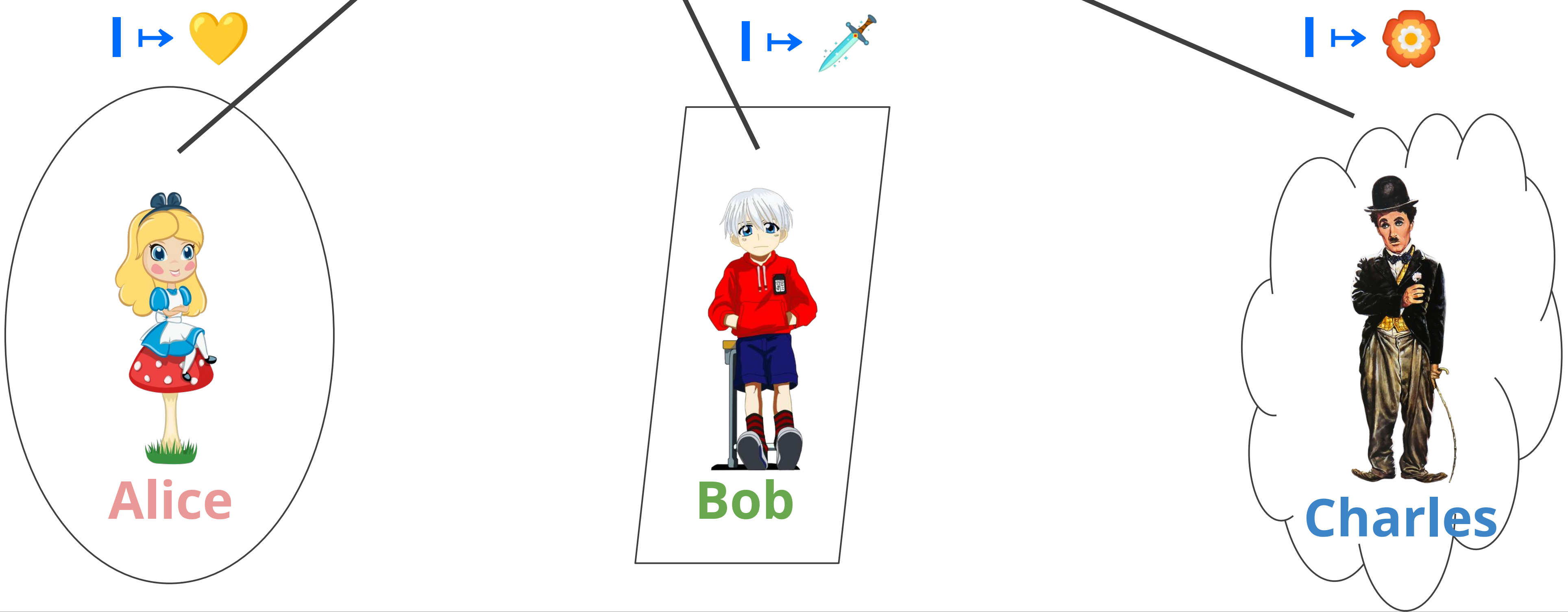
Local states?

Usually, l ↦ v means t

differently depending on one's local states!

But everyone has *secrets*!



Interpretation depends on local states

- not uncommon
  - in weak memory
  - in distributed systems
  - in virtual address spaces

$l \mapsto v$ depends on

- local caches
- local node states
- local page tables

- a solution: indexing resources by the local state $l \mapsto\{s\}\ v$

Alice

$l \mapsto\{A\}\ v :\approx$

$l \mapsto$ 💛

Bob

$l \mapsto\{B\}\ v :\approx l$

$\mapsto$ 🗡️

Charles

$l \mapsto\{C\}\ v :\approx$

$l \mapsto$ 🏵️

Indexing resources by local state: P s

- but not everything depends on some local states—local states should be *ambient*
  - hide local states with Iris' **monPred**
  - only work with local states explicitly when needed
    - using ***modalities***, inspired by Iris-based weak-mem works
- benefits:
  - cleaner for things that don't care about local states
  - more idiomatic reasoning with explicit local states

examples coming in a moment …

But what about *composing* local states?

weak-mem ➕ virtual address ➕ ???

- how to compose a logic that knows about weak-mem and a logic that knows about virtual address?
- open world problem, similar to `inG`

WIP: Monotone Lenses

weak-mem ✚ virtual address ✚ ???

solution:

1. generalizing monPred with *monotone lenses* to encode that the local state type embeds some concrete local state type
2. generalizing monPred modalities to lens-induced *families* of modalities
3. generalizing invariants and ghost ownership

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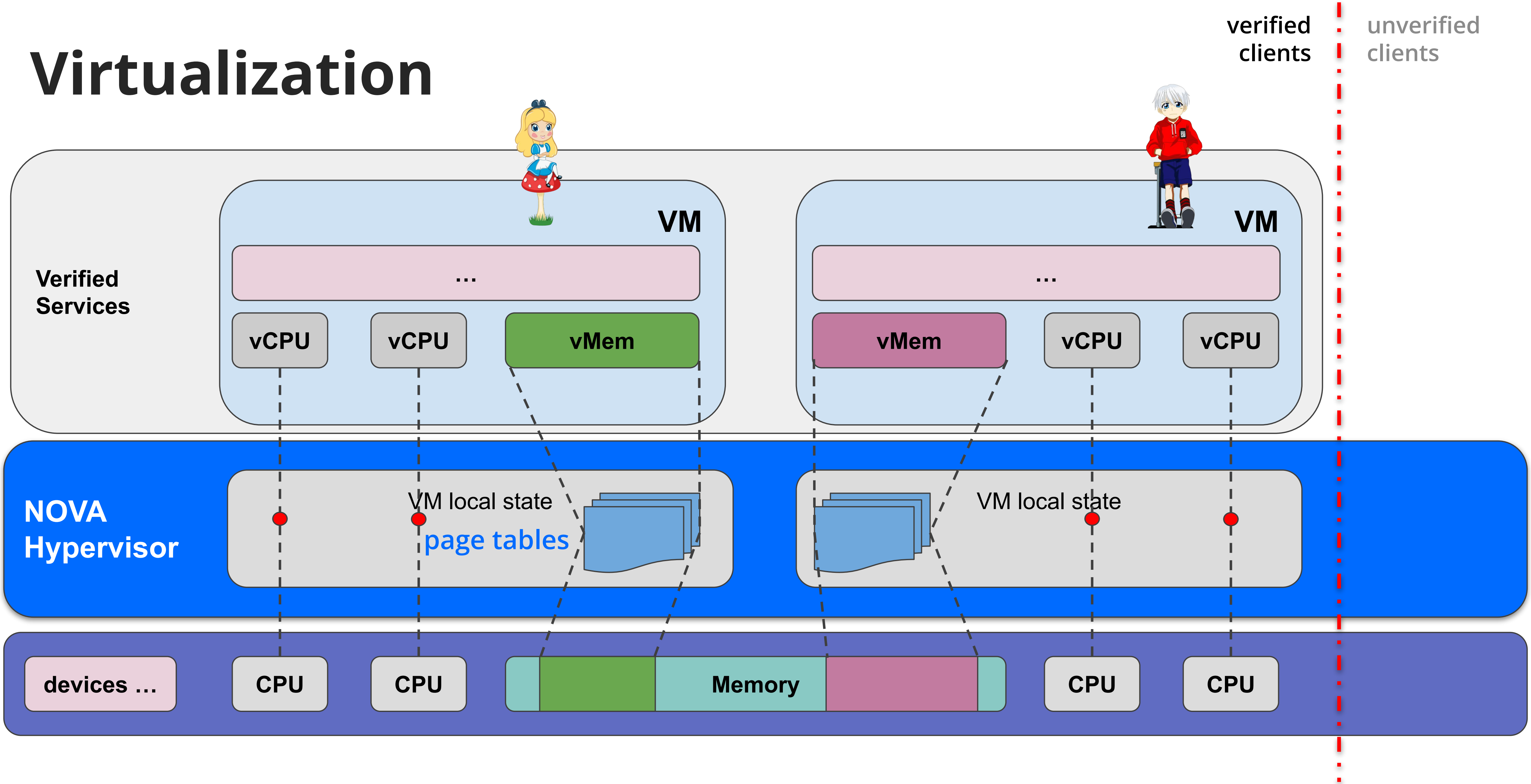
EXAMPLE:
VIRTUAL ADDRESS SPACES

Virtualization



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Example: virtual address spaces

➡ goal: building a points-to ownership for a VM's memory

$va \mapsto v \quad :\approx \; \exists\; pa,\; va \mapsto_{AS} pa * pa \mapsto v$

- va : virtual machine address
- pa : physical machine address

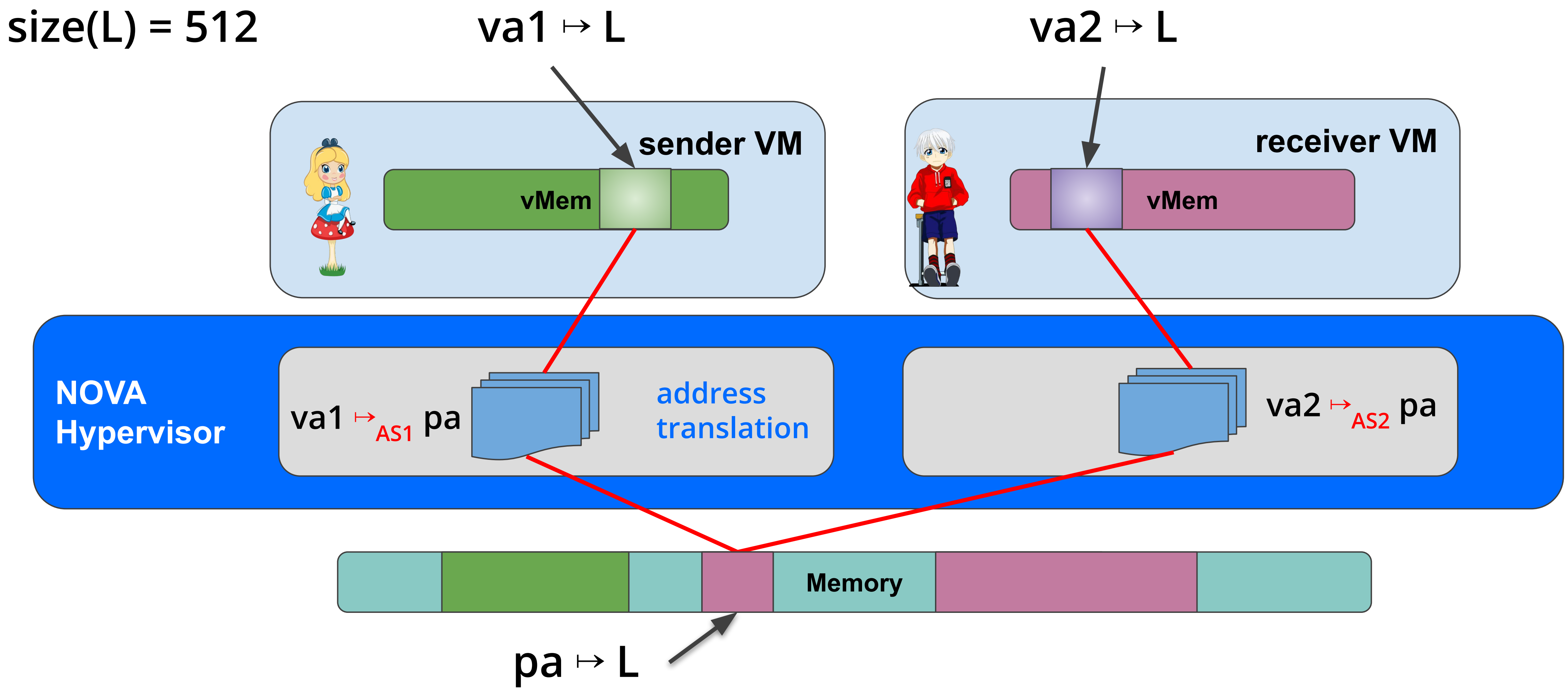
$va \mapsto_{AS} pa$:≈ in the *current* virtual address space AS,
va is mapped to pa

Page tables are local states of an address space

Building virtual points-to

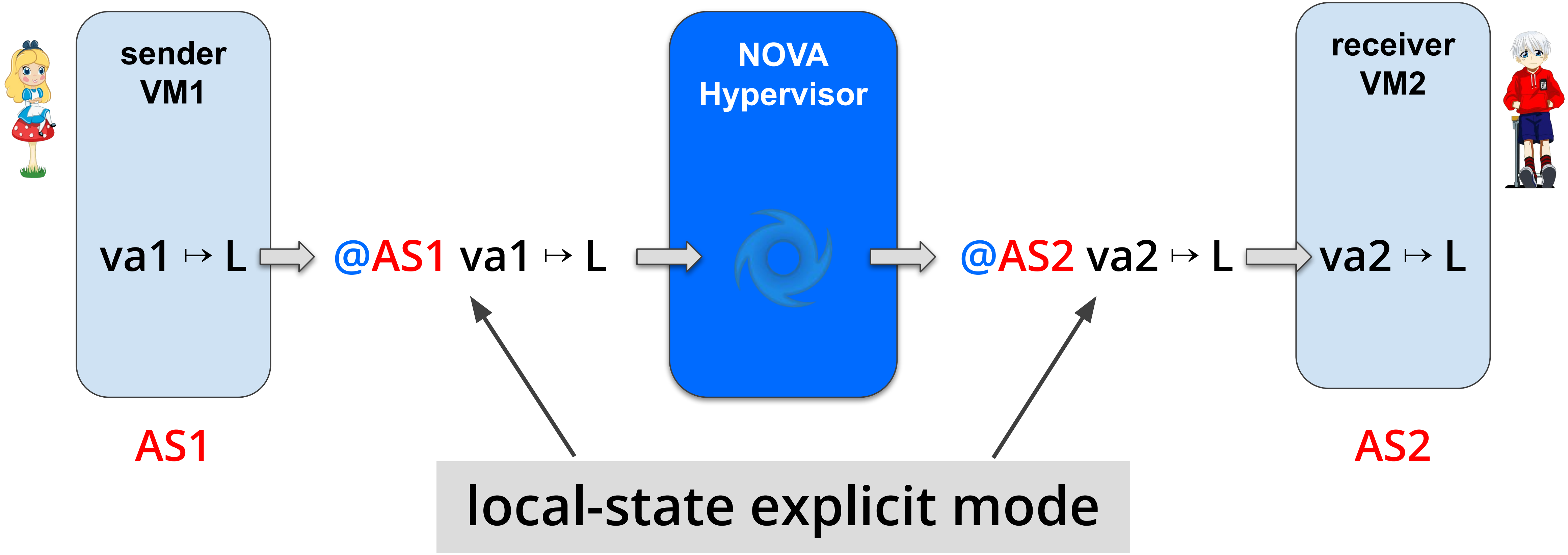
- aProp := monPred AddrSpace iProp
  - ≈ AddrSpace → iProp, but "monotone"
- $va \mapsto v$: aProp :≈ λ AS, $\exists$ pa, $va \mapsto_{AS} pa \ast pa \mapsto v$
- for those *without* interesting interaction with AS, same rules:
  - $\{ va \mapsto v \} \ast va \{ w.\ w = v \ast va \mapsto v \}$
- *with* interesting interactions with page tables, use ⎕AS and @AS P
  - state-explicit *modalities* inspired by Iris-based weak-mem works

Example: send memory across VMs



Logically,

size(L) = 512



Quick summary: a recipe for local states in Iris

- tProp := monPred I iProp, where I is the type of the local state
- for those *without* interesting interactions with the local state,
  - lift rules for tProp
  - pro: same rules as before
- for those *with* interesting (non-local) interactions,
  - explicit reasoning with local-state modalities (eg., ∃i, @i P)
  - *spoiler*: adjustments for invariants and ghost ownership

MONOTONE LENSES

Composing local states

Composing local states?

weak-mem + virtual address + ???

weak-mem	virtual address	???
vProp	aProp	
logic that knows about weak-mem states	logic that knows about address translation	future logics

➔ **idea:** work with some general tProp and, as needed, assume that tProp "embeds" vProp and/or aProp and/or others.

Generalizing the local state

➔ **idea:** work with some general tProp and, as needed, assume that tProp "embeds" vProp and/or aProp and/or others.

- idea in "typeclass" style:
  - have tProp as the assertion type
  - need weak-mem? assume HasVProp tProp
  - need address space? assume HasAProp tProp
- *lightweight* implementation with monPred
  - quantify over arbitrary local state type I: ∀ I, monPred I iProp (≈ tProp)
  - when needed, assume I "embeds" View (weak-mem states) and/or AddrSpace (address-translation states)

Monotone Lenses

```
Context {I : biIndex} {PROP: bi}.
Notation tProp := monPred I PROP.
```

“I embeds the address-translation states AddrSpace“

≈ the existence of a *monotone lens* from I into AddrSpace

Context {L_{AS} : I -ml> AddrSpace}.

💡 Monotonicity to fit monPred, crucial for stability of the frame.

Monotone Lenses

Context {I : biIndex} {PROP: bi}.

Notation tProp := monPred I PROP.

Context {J : biIndex} {L : I -ml> J}.

```
Structure MLens (I J : biIndex) : Type := MLensMake {
 mlens_get : I -> J ;
 mlens_set : J -> I -> I ;
 mlens_get_set : ∀ i j, mlens_get (mlens_set j i) = j ;
 mlens_set_get : ∀ i, mlens_set (mlens_get i) i = i ;
 mlens_set_set : ∀ i j1 j2, mlens_set j1 (mlens_set j2 i) = mlens_set j1 i ;
 mlens_get_mono : Proper ((⊑) ==> (⊑)) mlens_get ;
 mlens_set_mono : Proper ((⊑) ==> (⊑) ==> (⊑)) mlens_set ;
}.
```

Operations on lenses:

- product/projection
- compose
- equivalence
- disjointness
- inclusion
- L_{id} as a unit

Families of modalities

```
Context {I  : biIndex} {PROP: bi}.

Notation tProp := monPred I PROP.

Context {J : biIndex} {L : I -ml> J}.
```

- Resources that are local-state independent simply ignore I
- Resources that depend on some local-state J use J's family of modalities

@(L,j) P : tProp :≈

P holds at a local state whose J component is j

⊒{L} j : tProp :≈

The current local state's J component is at least j

- + more modalities
- interactions between families

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INVARIANTS and GHOST OWN

with lenses

Invariants and ghost ownership?

weak-mem + virtual address + ???

vPropr is wrong—

vProp

logic that knows about weak-mem states

aProp

logic that knows about address translation

future logics

tProp

Problem: BI-general invariants and ghost own

- Each lens-dependent monPred benefits from invariants and ghost own
  - Iris invariants and ghost ownership are tied to iProp
- Generalization: BI with own

```
Class HasOwn {PROP : bi} {A : cmra} : Type := {
 own            : gname → A → PROP ;
 own_op         : ∀ γ (a b : A), own γ (a ⋅ b) ⊣⊢ own γ a ∗ own γ b ;
 own_mono       :> ∀ γ, Proper (flip (≼) ==> (⊢)) (own γ) ;
 own_ne         :> ∀ γ, NonExpansive (own γ) ;
 own_timeless :> ∀ γ (a : A), Discrete a → Timeless (own γ a) ;
 own_core_persistent :> ∀ γ a, CoreId a → Persistent (own γ a)
}.
```

```
Class HasOwnValid `{!BiEmbed siPropI PROP} `{!HasOwn PROP A} ...
Class HasOwnUpd `{!BiBUpd PROP} `{!HasOwn PROP A} ...
Class HasOwnUnit `{!BiBUpd PROP} {A : ucmra} `{!HasOwn PROP A} ...
```

➡ more use of siProp

- Generalization: *with* modalities, invariants are general *except* for allocation

```
Definition inv_def N (P : PROP) : PROP :=
   (□ ∀ E : coPset, ⌜↑N ⊆ E⌝ → |={E,E ∖ ↑N}=> ▷ P ∗ (▷ P ={E ∖ ↑N,E}=∗ emp))%I.
```

Invariants for monPred's

- Iris invariants are lifted into objective invariants for monPred
  - resources stored in invariants must be independent of the local state I
  - Objective P := ∀ i1 i2, P i1 ⊢ P i2
  - Objective (@i P)
  - ALLOC: **Objective P** → ▷ P ⊢ |={E}=> inv N P
  - INTRO: P ⊢ ∃ s, ⊒i ∗ @i P
  - ELIM: @i P ⊢ ⊒i -∗ P

- generalization for lenses:
  - ObjectiveWith L P := ∀ (i : I) (j : J), P i ⊢ P i[L := j]
  - P is independent of the J component of the local state
  - *Components whose local states only differ in J can communicate* P *freely*
    - $@(L_{cpu}$, c) l ↦ v can be shared across CPUs that are in the same address space
  - Derived notion of *local invariants*
    - $@(L_{cpu}$, c) l ↦ v can be put in AS-local invariants

Problems

- BI-general invariants and ghost ownership
- Algebra of lenses ❓
  - interactions of families of modalities
- Adequacy of wp ❓
- biIndex that depends on the logic ❓
  - an abstraction from one lens to another that depends on the logic
  - similar to higher-order ghost state
- Cross-BI modalities ❓
  - lenses generalize I in monPred I PROP
  - what about PROP? from monPred I PROP1 to monPred I PROP2?
    - at BedRock, `mpred` to `Rep`.
- Proofmode/Automation ❓

CONCLUSION

- monPred to hide local states and local-state modalities to expose them when needed
- monotone lenses to abstract over and compose local states
- generalized invariants and ghost ownership as useful features of BIs
- work-in-progress, with quite a few TODOs

THANK YOU

Local states?

```
{ isLock(s, P) }
    s.lock();
{ P }
    …
    …
    …
{ isLock(s, P) * P }
    s.unlock();
{ emp }
```

temporarily owning P *locally*

❌ not the kind of "local" we focus on here

Local states?

```
#foo.hpp
static int x = 0;
class foo {
    int f() { … ; x = 1; … }
};
```

compilation-unit local statics

```
#bar.cpp
int bar() {
    int arr[N];
    …
};
```

thread-local stack variables

➡ often modeled as *explicit* resources (points-to)

Implicit local states

Local states are ambient:

1. they are always around/readily available
   - by threading through weakest-pre
   - more abstractly, by using non-atomic invariants

2. they should be unobtrusive
   - by hiding them with Iris' monPred

Example: weak memory in Iris

explicit ownership of the local state

a View—presenting the local cache of a CPU

$$\{\ tid \mapsto V * P\ V\ \}\ e \text{ on } tid\ \{\ (v, V').\ tid \mapsto V' * Q\ V'\ \}$$

- Most things don't care about the view V, only memory accesses do
- In many cases, memory accesses do not have interesting interactions with the view V

➡ Motivation for hiding views, and only let them bubble up when it's "interesting".

Implicit weak memory states in Iris

resources may depend on the local state

$$\{\ tid \mapsto V * P\ V\ \}\ e \text{ on } tid\ \{\ (v, V').\ tid \mapsto V' * Q\ V'\ \}$$

⇓

$$\{\ P\ \}\ e\ \{\ v.\ Q\ \}$$

$P\ Q$: monPred View iProp ≈ View → iProp, but “monotone”

$wp\ e\ \{\ v.\ Q\ \}$: monPred View iProp :≈

$$\lambda V,\ \ \forall\ tid,\ tid \mapsto V \mathrel{-\!\!*} wp\ e \text{ on } tid\ \{\ (v, V').\ tid \mapsto V' * Q\ V'\ \}$$

Implicit weak memory states in Iris

P Q : monPred View iProp ≈ View → iProp, but "monotone"

completely local
unobtrusive

$\{ \text{emp} \}\ z1 + z2\ \{ v.\ \ulcorner v = z1 +_Z z2 \urcorner \}$

$\{ l \mapsto \_ \}\ l :=_{na} v\ \{ l \mapsto v \}$

non-local cross-core communication❓

$\{ l \mapsto_{at} \_ \}\ l :=_{at} v\ \{ \exists V * l \mapsto_{at} (v,V) \}$

$\{ l \mapsto_{at} (v,V) \}\ *^{at} l\ \{ v.\ l \mapsto_{at} (v,V) * \exists V \}$

the local state *temporarily* explicit with *modalities*

Communicating local-state dependent resources

$\{ l \mapsto_{at} \_ \}\ l :=_{at} v\ \{ \exists V * l \mapsto_{at} (v,V) \}$

➡ releasing resources: $\{ P * l \mapsto_{at} \_ \}\ l :=_{at} v\ \{ \exists V * @V\ P * l \mapsto_{at} (v,V) \}$

implicitly local-state dependent

explicitly local-state dependent

$\{ l \mapsto_{at} (v,V) \}\ *^{at}l\ \{ v.\ \ l \mapsto_{at} (v,V) * \exists V \}$

➡ acquiring resources: $\{ @V\ P * l \mapsto_{at} (v,V) \}\ *^{at}l\ \{ v.\ \ l \mapsto_{at} (v,V) * \exists V * P \}$

Some properties

INTRO: P ⊢ ∃ j, ⊒{L}j ∗ @(L,j) P

ELIM: @(L,j) P ⊢ ⊒{L}j -∗ P

COMM: Lj ## Lk → @(Lj,j) @(Lk,k) P ⊣⊢ @(Lk, k) @(Lj, j) P