Karlsruher Institut für Technologie

Bitte Logo über \grouplogo{} festlegen.

Corten: Refinement Types for Imperative Languages with Ownership

Abschlusspräsentation Masterarbeit

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Inhaltsverzeichnis

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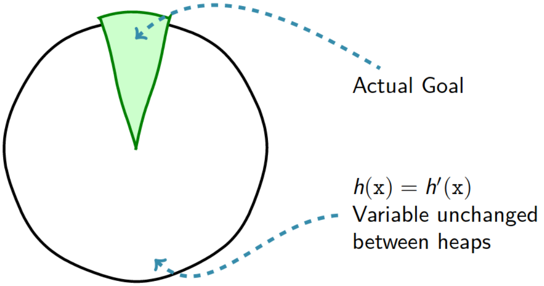
2. Type System
3. Soundness Justification
4. Related Work
5. Conclusion / Future Work

Motivation

```
public IntList square(IntList list) {
  return list.map(x -> x*x);
}
```



Motivation

```rust
fn max(a: i32, b: i32) {
  if a > b { a } else { b }
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- Return Value $(v) : v \geq a \wedge v \geq b$

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- Return Value $(v) : v \geq a \wedge v \geq b$
- Rondon et al. [RKJ08]: Refinement Types for Functional Programming Languages

Motivation

```
//@ max(a: i32, b: i32) -> {v:i32 | v >= a && v >= b }
fn  max(a: i32, b: i32) -> i32 {
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fn  max(a: i32, b: i32) -> i32 {
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}
```

let $\Gamma = (a : \{v : \texttt{i32} \mid \text{true}\}, b : \{v : \texttt{i32} \mid \text{true}\})$ and $\tau = \{v : \texttt{i32} \mid v \geq a \land v \geq b\}$

$$\frac{}{\Gamma \vdash \texttt{if}\ a > b\ \{a\}\ \texttt{else}\ \{b\} : \tau}$$

Motivation

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fn  clamp(a: &mut i32, b: i32) {
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```
fn clamp(a: &mut i32, b: i32) {
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}
fn client(...) {
  ...
  clamp(&mut x, 5);
  clamp(&mut y, 6);
  print!(x);
  ...
}
```

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fn  clamp(a: &mut i32, b: i32) {
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What does this it `print(x)` output?

- In most imperative programming languages:
  - Could be: old `x` or `5`

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What does this it `print(x)` output?

- In most imperative programming languages:
  - Could be: old `x` or `5`
  - But also `6` (if x aliases with y)!
- In Rust:
  - Just old `x` or `5`
  - And nothing else!

Motivation

```
fn  clamp(a: &mut i32, b: i32) {
  // borrows a
  // owns b
  if *a > b { *a = b }
  // "returns" the borrow of a
}
fn  client(...) { // owns x, y
  ...
  clamp(&mut x, 5); // lend x mutably
  clamp(&mut y, 6); // lend y mutably
  print!(x);
  ...
}
```

Ownership in Rust: Mutability XOR Aliasing

Each lexical scope tracks permissions for visible memory objects. Possible Permission Levels:

- Owner (e.g. `b`)
  - can: read, write
  - transfer ownership (if no outstanding borrows)
- Mutable Reference (e.g. `&mut x`)
  - can: read, write
  - guarantee: no aliasing
- Immutable Reference (e.g. `&v`)
  - can: read, alias
  - guarantee: no mutation

Motivation

Consequences:

- unique data owner
- no global, mutable state
- no cycles in memory structure

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- safe non-gc memory management
- safe concurrency
- safe low-level hardware access
- ...

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- safe low-level hardware access
- ...
- $\Rightarrow$ show: program verification as well

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Contributions

- Empirical Use-Case Analysis
- Refinement Type System
  - Automatic & Decidable Type Checking
  - Path Sensitivity
  - Mutable Data & References
  - Modularity
  - Partial Mechanized Proof of Soundness
- Implementation
  - Accessible Interface
  - Type-Error Messages with Source Code Locations
  - Counter-Example Generation
- Evaluation
  - Automatic Verification of non-trivial Programs
  - Comparison to other tools

Refinement Types for Rust – Syntax

```
fn max(a: i32, b: i32) -> i32 {
  if a > b { a } else { b }
}
```

Addition of two macros

- `ty!`$\{l : b \mid \varphi\}$ in place of a type
- `relax_ctx!{ ... }` in place of a statement

Refinement Types for Rust – Syntax

```
fn max(
  a: ty!{ av: i32 | true },
  b: ty!{ bv : i32 | true }
) -> ty!{ v : i32 | v >= av && v >= bv } {
  if a > b { a } else { b }
}
```

Addition of two macros

- `ty!`$\{l : b \mid \varphi\}$ in place of a type
- `relax_ctx!{ ... }` in place of a statement

Refinement Types for Rust – Syntax

```
fn max(
  a: ty!{ av: i32 },
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}
```

Addition of two macros

- `ty!`$\{l : b \mid \varphi\}$ in place of a type
- `relax_ctx!{ ... }` in place of a statement

Type Updates

```
fn decr() -> ty!{ w : i32 | w >= 0 } {
 let mut i = ... as ty!{ v: i32 | v > 0};
 i = i - 1;
 i
}
```

- Types need to change through execution
  - $\Rightarrow$ type updates
  - Separation of program-variables and logic-variables
  - Γ association of program- to logic-variables and predicate
  - $\Gamma \vdash s \Rightarrow \Gamma'$ (Statement Type Checking)
  - $\Gamma \vdash e : \tau$ (Expression Typing)
  - on assignment: *replace* association, *append* predicate
  - observation: assignment can not invalidate existing predicates

Type Updates

```
fn decr() -> ty!{ w : i32 | w >= 0 } {
  // Γ₁ = ({} , true)
  let mut i = ... as ty!{ v: i32 | v > 0};
  // Γ₂ = ({i ↦ v} , v > 0)
  i = i - 1;
  // Γ₃ = ({i ↦ v₂} , v > 0 ∧ v₂ ≐ v − 1)
  i }
```

- Types need to change through execution
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  - on assignment: *replace* association, *append* predicate
  - observation: assignment can not invalidate existing predicates

Type Updates

```
fn decr() -> ty!{ w : i32 | w >= 0 } {
  // Γ1 = ({}, true)
  let mut i = ... as ty!{ v: i32 | v > 0};
  // Γ2 = ({i ↦ v}, v > 0)
  i = i - 1;
  // Γ3 = ({i ↦ v2}, v > 0 ∧ v2 ≐ v − 1)
  i }
```

$$\textsc{Intro-Sub}\ \frac{\Gamma \vdash e : \tau \qquad \Gamma \vdash \tau \preceq \tau'}{\Gamma \vdash e \ \mathtt{as}\ \tau' : \tau'}$$

$$\textsc{Decl}\ \frac{\Gamma \vdash e : \{\beta : b \mid \varphi\}}{\Gamma \vdash \mathtt{let}\ x = e \Rightarrow \Gamma[x \mapsto \beta], \varphi}$$

Type Updates

```
fn decr() -> ty!{ w : i32 | w >= 0 } {
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  i }
```

$$\textsc{BinOp}\ \frac{\Gamma \vdash \alpha \text{ fresh}}{\Gamma \vdash x_1 \odot x_2 : \{\alpha : b \mid \alpha \simeq [\![x_1 \odot x_2]\!]\Gamma\}}$$

$$\textsc{Assign}\ \frac{\Gamma \vdash e : \{\beta : b \mid \varphi\}}{\Gamma \vdash x = e \Rightarrow \Gamma[x \mapsto \beta], \varphi}$$

Type Updates

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fn decr() -> ty!{ w : i32 | w >= 0 } {
  // Γ1 = ({}, true)
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  i }
```

$$\textsc{Seq}\ \frac{\Gamma \vdash s_1 \Rightarrow \Gamma' \qquad \Gamma' \vdash s_2 \Rightarrow \Gamma''}{\Gamma \vdash s_1 ; s_2 \Rightarrow \Gamma''}$$

References – Strong Updates

```
fn client() -> ty!{ v: i32 | v == 4 } {
  let a = 2;       // a : {v₁ : i32 | v₁ == 2}
  let b = &mut a;  // b : {v₂ : &i32 | v₂ == &a}
  *b = 0; // changes a's value and type
  let c = &mut b;  // c : {v₃ : &i32 | v₃ == &b}
  **c = 4; // changes a's value and type
  a
}
```

References – Strong Updates

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fn client() -> ty!{ v: i32 | v == 4 } {
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  **c = 4; // changes a's value and type
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}
```

$$\textsc{Lit}\ \frac{\Gamma \vdash \alpha \text{ fresh}}{\Gamma \vdash v : \{\alpha : b \mid \alpha \simeq [\![v]\!]\Gamma\}}$$

References – Strong Updates


```
fn client() -> ty!{ v: i32 | v == 4 } {
  let a = 2;         // a : {v1 : i32 | v1 == 2}
  let b = &mut a;    // b : {v2 : &i32 | v2 == &a}
  *b = 0; // changes a's value and type
  let c = &mut b;    // c : {v3 : &i32 | v3 == &b}
  **c = 4; // changes a's value and type
  a
}
```

$$\textsc{Ref}\ \frac{\Gamma \vdash \alpha \text{ fresh}}{\Gamma \vdash \&x : \{\alpha : \&b \mid \alpha \simeq [\![\&x]\!]\Gamma\}}$$

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```

$$\textsc{Assign-Strong}\ \frac{\Gamma(z) = \beta \qquad \Gamma \vdash x \in \{\&y\} \qquad \Gamma \vdash \gamma \text{ fresh}}{\Gamma \vdash *x = z \Rightarrow \Gamma[y \mapsto \gamma], \gamma \doteq \beta}$$

(Also Assign-Weak)

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}
```

$$\textsc{Var}\ \frac{\Gamma \vdash \alpha \text{ fresh}}{\Gamma \vdash x : \{\alpha : b \mid \alpha \simeq [\![x]\!]\Gamma\}}$$

Mutable Arguments

```
fn clamp(a: &mut ty!{ a1 : i32 | true => a2 | a2 <= b1 }, b: ty!{ b1: i32 }) {
  if *a > b { *a = b }
}
fn client(...) {
  ...
  clamp(&mut x, 5);
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  print!(x);
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Mutable Arguments

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fn clamp(
  a: &mut ty!{ a1 : i32 | true => a2 | a2 <= b1 },
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  // Γ1 = ({a ↦ v1, arg0 ↦ a1, b ↦ b1},
  //                v1 ≐ &arg0 ∧ true ∧ true)
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  // Γ2 = ({a ↦ v1, arg0 ↦ v2, b ↦ b1},
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Mutable Arguments

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```

- `ty!` $\{\alpha : \mathsf{b} \mid \varphi \Rightarrow \beta \mid \psi\}$
- Callee requires φ for reference destination α
- Callee ensures ψ for reference destination β
- Of course, multiple arguments possible

Mutable Arguments

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Sub-Context

```
fn clamp(
  a: &mut ty!{ a1 : i32 | true => a2 | a2 <= b1 },
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- still left: proof obligation from signature $a_2 \leq b_1$
- i.e. is Γ_2 a valid end-state?

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- generalize notion of sub-types to context: sub-context

Sub-Context

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  b: ty!{ b1: i32 }
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  // Γ₁ = ({a ↦ v₁, arg₀ ↦ a₁, b ↦ b₁},
  //              v₁ ≐ &arg₀ ∧ true ∧ true)
  if *a > b { *a = b }
  // Γ₂ = ({a ↦ v₁, arg₀ ↦ v₂, b ↦ b₁},
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- expected state: $\Gamma_e = (\{arg_0 \mapsto a_2, b \mapsto b_1\}, a_2 \le b_1)$

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}
```

- still left: proof obligation from signature $a_2 \leq b_1$
- i.e. is Γ_2 a valid end-state?
- generalize notion of sub-types to context: sub-context
- expected state: $\Gamma_e = (\{arg_0 \mapsto a_2, b \mapsto b_1\}, a_2 \leq b_1)$
- show: $\Gamma_2 \preceq \Gamma_e$

Sub-Context

$$\preceq\text{-}\textsc{Ctx}\ \frac{\vDash \Phi'[\mu'(x) \triangleright \mu(x) \ \mid x \in \mathrm{dom}(\mu')] \rightarrow \Phi \qquad \mathrm{dom}(\mu') \subseteq \mathrm{dom}(\mu)}{(\mu, \Phi) \preceq (\mu', \Phi')}$$

- still left: proof obligation from signature $a_2 \leq b_1$
- i.e. is Γ_2 a valid end-state?
- generalize notion of sub-types to context: sub-context
- expected state: $\Gamma_e = (\{arg_0 \mapsto a_2, b \mapsto b_1\}, a_2 \leq b_1)$
- show: $\Gamma_2 \preceq \Gamma_e$

Mutable Calls

```
fn client(...) {
  ...
  // Γ1 = ({x ↦ v1, y ↦ v2}, ...)
  clamp(&mut x, 5);
  // Γ2 = ({x ↦ v3, y ↦ v2}, ... ∧ v3 ≤ 5)
  clamp(&mut y, 6);
  // Γ3 = ({x ↦ v3, y ↦ v4}, ... ∧ v3 ≤ 5 ∧ v4 ≤ 6)
  print!(x);
  ...
}
```

- append predicates from callee to context
- update association of logic variables

SMT Request

...

Example Error Message

...

Ecosystem Integration

...

Soundness

Karlsruher Institut für Technologie

Progress

If $\Gamma \vdash s_1, \sigma : \Gamma \Rightarrow \Gamma_2$ and $s_1 \neq \texttt{unit}$, then there is a s_2 and σ_2 with $\langle s_1 \mid \sigma_1 \rangle \rightsquigarrow \langle s_2 \mid \sigma_2 \rangle$.

Corten strictly refines the base language, therefore progress depends on base type system.

Preservation

If $\Gamma \vdash s \Rightarrow \Gamma_2, \sigma : \Gamma$ and $\langle s \mid \sigma \rangle \rightsquigarrow \langle s_1 \mid \sigma_1 \rangle$, then there is a Γ_1 with $\Gamma_1 \vdash s_1 \Rightarrow \Gamma_2$ and $\sigma_2 : \Gamma_2$

Stronger property than base language preservation: Show that refined types are preserved

State Conformance

State Conformance $\sigma : \Gamma$

A state σ is conformant with respect to a typing context $\Gamma = (\mu, \Phi)$ (written as $\sigma : \Gamma$), iff:

$$\Phi[\mu(x) \triangleright [\![\sigma(x)]\!] \mid x \in \mathrm{dom}(\mu)] \text{ is satisfiable}$$

I.e. a conformant type context does not contradict the execution state.

Examples:

- If $\sigma : (\emptyset, \Phi)$ then Φ is satisfiable
- If $\sigma : (\mu, \Phi_1 \wedge \Phi_2)$ then $\sigma : (\mu, \Phi_1)$ and $\sigma : (\mu, \Phi_1)$.
- If $\sigma : (\mu, \Phi)$ and $\mathrm{FV}(\Phi) \subseteq \mathrm{dom}(\mu)$, then $\models \Phi[\mu(x) \triangleright [\![\sigma(x)]\!] \mid x \in \mathrm{dom}(\mu)]$

Intermediate Steps

Conformance of Symbolic Execution

If $\sigma : \Gamma$, $\Gamma \vdash \alpha$ fresh then $\sigma[x \mapsto [\![e]\!]\sigma] : \Gamma[x \mapsto \alpha], (\alpha \simeq [\![e]\!]\Gamma)$

where $(\alpha \simeq [\![e]\!]\Gamma)$ is the symbolic execution of e equated with α in context Γ

Reference Predicates are Conservative

If $\sigma : \Gamma$ and $\Gamma \vdash *x \in \{y_1, \ldots, y_n\}$ then $[\![\sigma(x)]\!] = \&y_i$ for some $i \in 1, \ldots, n$

Rare case where conservative typing requires

Sub-Context Relation is Conservative

If $\Gamma \preceq \Gamma'$ and $\sigma : \Gamma$ then $\sigma : \Gamma'$

Related Work

Refinement Types and Mutability

- Rondon et al. [RKJ10], Bakst and Jhala [BJ16]: Refinement Types for C subset. Lack of guarantees requires ad-hoc mechanisms to control aliasing
- Lanzinger [Lan21]: Property Types in Java (only immutable). Bachmeier [Bac22]: Extension using Ownership System
- Toman et al. [Tom+20] (ConSORT): Fractional Ownership, strong and weak updates

Rust verification

- Ullrich [Ull16]: Translation to Lean; linear mutation chain. Denis et al [DJM21] similar, but to Why3
- Astrauskas et al. [Ast+19] (Prusti): heavy-weight verification, translation to separation logic (Viper)
- Matsushita et al. [MTK20] (RustHorn): constrained Horn clauses

Related Work: Flux – Refinement Types for Rust

- MIR vs. HIR
- specification in comments vs. embedding in types
- context inclusions vs. sub context
- distinction strong and weak references vs. dynamic choice by typ checking rules
- explicit introduction of logic variables vs. ad-hoc
- formalization based on RustBelt vs. formalization based on own language
- missing in Corten: records & inference
- otherwise: similar capabilities

Future Work

- Records & ADTs
- Predicate Generics (Abstract Predicates)
- Concurrency using Predicate Generics?

Conclusion

- Working Refinement Type System for Rust with Mutability
- Minimal Interface
- Soundness Justification
- Evaluation

Literatur

[1] Vytautas Astrauskas u. a. „Leveraging rust types for modular specification and verification“. In: *Proceedings of the ACM on Programming Languages* 3 (OOPSLA 10. Okt. 2019), S. 1–30. ISSN: 2475-1421. DOI: `10.1145/3360573`. URL: `https://dl.acm.org/doi/10.1145/3360573` (besucht am 23. 02. 2022).

[2] Joshua Bachmeier. *Property Types for Mutable Data Structures in Java*. 2022. DOI: `10.5445/IR/1000150318`. URL: `https://publikationen.bibliothek.kit.edu/1000150318` (besucht am 03. 10. 2022).

[3] Alexander Bakst und Ranjit Jhala. „Predicate Abstraction for Linked Data Structures“. In: *Verification, Model Checking, and Abstract Interpretation*. Hrsg. von Barbara Jobstmann und K. Rustan M. Leino. Lecture Notes in Computer Science. Berlin, Heidelberg: Springer, 2016, S. 65–84. ISBN: 978-3-662-49122-5. DOI: `10.1007/978-3-662-49122-5_3`.

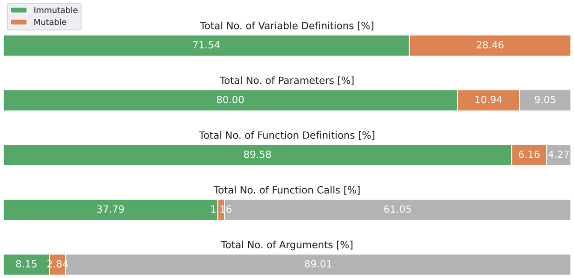
[4] Xavier Denis, Jacques-Henri Jourdan und Claude Marché. „The Creusot Environment for the Deductive Verification of Rust Programs“. Diss. Inria Saclay-Île de France, 2021.

[5] Florian Lanzinger. „Property Types in Java: Combining Type Systems and Deductive Verification“. Master Thesis. Karlsruher Institut für Technologie, Feb. 2021.

[6] Yusuke Matsushita, Takeshi Tsukada und Naoki Kobayashi. „RustHorn: CHC-based verification for Rust programs“. In: *European Symposium on Programming*. Springer, Cham, 2020, S. 484–514.

Empirical Use-Case Analysis

- public open-source code (crates.io)
- about 64 million lines of Rust code
- syntactical analysis



`decr` Typing Tree

let $\Gamma_2 = \Gamma[i \mapsto v_1], v > 0$ and $\tau = \{v : \texttt{i32} \mid v > 0\}$

$$
\textsc{Seq}\ \dfrac{
\textsc{Decl}\ \dfrac{
\textsc{Intro-Sub}\ \dfrac{\Gamma_1 \vdash \ldots : \tau' \qquad \Gamma_1 \vdash \tau' \preceq \tau}{\Gamma_1 \vdash \texttt{... as } \tau : \tau}
}{\Gamma_1 \vdash \texttt{let i = ... as } \tau \Rightarrow \Gamma_2}
\qquad
\textsc{Ass}\ \dfrac{
\textsc{BinOp}\ \dfrac{\Gamma_1 \vdash v_2 \text{ fresh}}{\Gamma_1 \vdash \texttt{i - 1} : \{v_2 : \mathrm{i32} \mid v_2 \doteq v - 1\}}
}{\Gamma_2 \vdash \texttt{i = i - 1} \Rightarrow \Gamma[i \mapsto v_2], v > 0, v_2 \doteq v - 1}
}{\Gamma_1 \vdash \texttt{let i = ... as } \tau\texttt{; i = i - 1} \Rightarrow \Gamma[i \mapsto v_2], v > 0, v_2 \doteq v - 1}
$$

Expression Typing $\Gamma \vdash e : \tau$

$$\textsc{Lit}\ \frac{\Gamma \vdash \alpha \text{ fresh}}{\Gamma \vdash v : \{\alpha : b \mid \alpha \simeq [\![v]\!]\Gamma\}} \qquad \textsc{BinOp}\ \frac{\Gamma \vdash \alpha \text{ fresh}}{\Gamma \vdash x_1 \odot x_2 : \{\alpha : b \mid \alpha \simeq [\![x_1 \odot x_2]\!]\Gamma\}}$$

$$\textsc{Var}\ \frac{\Gamma \vdash \alpha \text{ fresh}}{\Gamma \vdash x : \{\alpha : b \mid \alpha \simeq [\![x]\!]\Gamma\}} \qquad \textsc{Intro-Sub}\ \frac{\Gamma \vdash e : \tau \qquad \Gamma \vdash \tau \preceq \tau'}{\Gamma \vdash e \ \texttt{as}\ \tau' : \tau'}$$

Statement Type Checking $\Gamma \vdash s \Rightarrow \Gamma'$

$$\textsc{If}\ \frac{\Gamma, \Gamma(x) \doteq \texttt{true} \vdash s_t \Rightarrow \Gamma' \qquad \Gamma, \Gamma(x) \doteq \texttt{false} \vdash s_e \Rightarrow \Gamma'}{\Gamma \vdash \text{if } x \text{ then } s_t \text{ else } s_e \Rightarrow \Gamma'}$$

$$\textsc{Seq}\ \frac{\Gamma \vdash s_1 \Rightarrow \Gamma' \qquad \Gamma' \vdash s_2 \Rightarrow \Gamma''}{\Gamma \vdash s_1 ; s_2 \Rightarrow \Gamma''}$$

$$\textsc{Decl}\ \frac{\Gamma \vdash e : \{\beta : b \mid \varphi\}}{\Gamma \vdash \texttt{let}\ x = e \Rightarrow \Gamma[x \mapsto \beta], \varphi} \qquad \textsc{Assign}\ \frac{\Gamma \vdash e : \{\beta : b \mid \varphi\}}{\Gamma \vdash x = e \Rightarrow \Gamma[x \mapsto \beta], \varphi}$$

Expression Typing $\Gamma \vdash e : \tau$

$$\textsc{Ref}\ \frac{\Gamma \vdash \alpha \text{ fresh}}{\Gamma \vdash \&x : \{\alpha : \&b \mid \alpha \simeq [\![\&x]\!]\Gamma\}}$$

$$\textsc{Var-Deref}\ \frac{\Gamma \vdash x \in \{\&y\} \qquad \Gamma \vdash y : \tau}{\Gamma \vdash *x : \tau}$$

Statement Type Checking $\Gamma \vdash s \Rightarrow \Gamma'$

$$\textsc{Assign-Strong}\ \frac{\Gamma(z) = \beta \qquad \Gamma \vdash x \in \{\&y\} \qquad \Gamma \vdash \gamma \text{ fresh}}{\Gamma \vdash *x = z \Rightarrow \Gamma[y \mapsto \gamma], \gamma \doteq \beta}$$

Expression Typing $\Gamma \vdash e : \tau$

$$\textsc{Ref}\ \frac{\Gamma \vdash \alpha \text{ fresh}}{\Gamma \vdash \&x : \{\alpha : \&b \mid \alpha \simeq [\![\&x]\!]\Gamma\}}$$

$$\textsc{Var-Deref}\ \frac{\Gamma \vdash x \in \{\&y\} \qquad \Gamma \vdash y : \tau}{\Gamma \vdash *x : \tau}$$

Statement Type Checking $\Gamma \vdash s \Rightarrow \Gamma'$

$$\textsc{Assign-Strong}\ \frac{\Gamma(z) = \beta \qquad \Gamma \vdash x \in \{\&y\} \qquad \Gamma \vdash \gamma \text{ fresh}}{\Gamma \vdash *x = z \Rightarrow \Gamma[y \mapsto \gamma], \gamma \doteq \beta}$$

$$\textsc{Assign-Weak}\ \frac{\dfrac{\Gamma \vdash e : \tau}{\Gamma \vdash y_i : \{\beta_i : b_i \mid \varphi_i\}} \qquad \dfrac{\Gamma \vdash x \in \{\&y_1, \ldots, \&y_n\}}{\Gamma \vdash \tau \preceq \{\beta_i : b_i \mid \varphi_i\}}}{\Gamma \vdash *x = e \Rightarrow \Gamma}$$

Blöcke

in den KIT-Farben

Greenblock

Standard (`block`)

Blueblock

= `exampleblock`

Redblock

= `alertblock`

Brownblock

Purpleblock

Cyanblock

Yellowblock

Lightgreenblock

Orangeblock

Grayblock

Contentblock

(farblos)

Auflistungen

Text

- Auflistung
  Umbruch
- Auflistung
  - Auflistung
  - Auflistung

Bei Frames ohne Titel wird die Kopfzeile nicht angezeigt, und der freie Platz kann für Inhalte genutzt werden.

Bei Frames mit Option `[plain]` werden weder Kopf- noch Fußzeile angezeigt.

Beispielinhalt

Bei Frames mit Option `[t]` werden die Inhalte nicht vertikal zentriert, sondern an der Oberkante begonnen.

Beispielinhalt: Literatur

Farbpalette

kit-green100	kit-green90	kit-green80	kit-green70	kit-green60	kit-green50	kit-green40	kit-green30	kit-green25	kit-green20	kit-green15	kit-green10	kit-green5
kit-blue100	kit-blue90	kit-blue80	kit-blue70	kit-blue60	kit-blue50	kit-blue40	kit-blue30	kit-blue25	kit-blue20	kit-blue15	kit-blue10	kit-blue5
kit-red100	kit-red90	kit-red80	kit-red70	kit-red60	kit-red50	kit-red40	kit-red30	kit-red25	kit-red20	kit-red15	kit-red10	kit-red5
kit-gray100	kit-gray90	kit-gray80	kit-gray70	kit-gray60	kit-gray50	kit-gray40	kit-gray30	kit-gray25	kit-gray20	kit-gray15	kit-gray10	kit-gray5
kit-orange100	kit-orange90	kit-orange80	kit-orange70	kit-orange60	kit-orange50	kit-orange40	kit-orange30	kit-orange25	kit-orange20	kit-orange15	kit-orange10	kit-orange5
kit-lightgreen100	kit-lightgreen90	kit-lightgreen80	kit-lightgreen70	kit-lightgreen60	kit-lightgreen50	kit-lightgreen40	kit-lightgreen30	kit-lightgreen25	kit-lightgreen20	kit-lightgreen15	kit-lightgreen10	kit-lightgreen5
kit-brown100	kit-brown90	kit-brown80	kit-brown70	kit-brown60	kit-brown50	kit-brown40	kit-brown30	kit-brown25	kit-brown20	kit-brown15	kit-brown10	kit-brown5
kit-purple100	kit-purple90	kit-purple80	kit-purple70	kit-purple60	kit-purple50	kit-purple40	kit-purple30	kit-purple25	kit-purple20	kit-purple15	kit-purple10	kit-purple5
kit-cyan100	kit-cyan90	kit-cyan80	kit-cyan70	kit-cyan60	kit-cyan50	kit-cyan40	kit-cyan30	kit-cyan25	kit-cyan20	kit-cyan15	kit-cyan10	kit-cyan5