

Programmierparadigmen macht Spaß

Darius Schefer, Max Schik

Contents

Haskell	2
General Haskell stuff	2
Important functions	3
Lambda Calculus	4
General stuff	4
Primitive Operations	4
Equivalences	4
α -equivalence	4
η -equivalence	5
Reductions	5
β -reduction	5
Normal Form	5
Church-Rosser	5
Recursion	5
Evaluation Strategies	5
Typen	6
Regelsysteme	6
Typsysteme	6
Regeln	6
Forts. Typsysteme	7
Polymorphie	7
Typschema	7
Curry-Howard Isomorphism	7
Grundregeln	7
Allgemeines Vorgehen	7
β -reduction Beispiel:	7
Unifikation	8
Unifikator	8
Definition Unifikator	8
Definition mgu	8
Unifikationsalgorithmus: <code>unify(C) =</code>	8
Parallelprogrammierung	8
Flynn's Taxanomy	9
MPI	9
Communication Modes	9
Collective Operations	10
Java	11
Multithreading	11
Race conditions	11

Caching and code reordering	11
Functional programming	12
Executors	12
Streams	12
Example	12
Design by Contract	13
Liskov Substitution Principle	13
Compiler	13
Basics	13
Linksrekursion	14
Java Bytecode	14
General	14
Examples	16

Haskell

Haskell is great.

General Haskell stuff

```
-- type definitions are right associative
foo :: (a -> (b -> (c -> d)))
-- function applications are left associative
(((foo a) b) c) d

-- guards are unnecessary if you know how pattern matching works
foo x y
| x > y = "shit"
| x < y = "piss"
| x == y = "arschsekretlecker"
| default = "love"

-- case of does pattern matching so its okay
foo x = case x of
    [] -> "fleischpenis"
    [1] -> "kokern"
    (420:1) -> "pimpern"

-- list comprehension is not as good as in python
[foo x | x <- [1..420], x `mod` 2 == 0]

[0..5] == [0,1,2,3,4,5]

-- alias for pattern matching
foo l@(x:xs) = l == (x:xs) -- returns true

-- combine two functions
f :: a -> b
g :: b -> c

h :: a -> c
h = f . g

data Tree a = Leaf
```

```

| Node (Tree a) a (Tree a)
deriving (Show)
```

```
-- defines interface
class Eq t where
  (==) :: t -> t -> Bool
  (/=) :: t -> t -> Bool
  -- default implementation
  x /= y = not $ x == y
```

```
-- extends interface
class (Show t) => B t where
  foo :: (B t) -> String
```

```
-- implement interface
instance Eq Bool where
  True == True = True
  False == False = True
  True == False = False
  False == True = False
```

Important functions

```
-- maps a function to a list
map :: (a -> b) -> [a] -> [b]
-- filters a list with a predicate
filter :: (a -> Bool) -> [a] -> [a]
-- fold from left
foldl :: Foldable t => (b -> a -> b) -> b -> t a -> b
-- fold from right
foldr :: Foldable t => (a -> b -> b) -> b -> t a -> b
-- checks if a in collection
elem :: (Foldable t, Eq a) => a -> t a -> Bool
-- in a list of type [(key, value)] returns first element where key matches given value
lookup :: Eq a => a -> [(a, b)] -> Maybe b
-- repeated application of function
iterate :: (a -> a) -> a -> [a]
-- repeats constant in infinite list
repeat :: a -> [a]
-- applies function until the predicate is true
until :: (a -> Bool) -> (a -> a) -> a -> a
-- returns true if the predicate is true for at least one element
any :: Foldable t => (a -> Bool) -> t a -> Bool
-- return true if the predicate is true for all elements
all :: Foldable t => (a -> Bool) -> t a -> Bool
-- flips the parameters of a function
flip :: (a -> b -> c) -> b -> a -> c
-- combines two lists to a list of tuples
zip :: [a] -> [b] -> [(a, b)]
-- combines two lists with the given function
zipWith :: (a -> b -> c) -> [a] -> [b] -> [c]
```

Lambda Calculus

General stuff

- Function application is left associative $\lambda x. f x y = \lambda x. ((f x) y)$
- untyped lambda calculus is turing complete

Primitive Operations

Let

- let $x = t_1$ in t_2 wird zu $(\lambda x. t_2) t_1$

Church Numbers

- $c_0 = \lambda s. \lambda z. z$
- $c_1 = \lambda s. \lambda z. s z$
- $c_2 = \lambda s. \lambda z. s (s z)$
- $c_3 = \lambda s. \lambda z. s (s (s z))$
- etc...
- **Successor Function**
 - $\text{succ } c_2 = c_3$
- **Arithmetic Operations**
 - Plus: $\lambda m. \lambda n. \lambda f. \lambda x. m f (n f x)$
 - Minus: $\lambda m. \lambda n. n c_{pred} m$
 - isZero: $\lambda n. n (\lambda x. c_{false}) c_{true}$
 - Times: $\lambda m. \lambda n. \lambda f. m (n f)$
 - Exp: $\lambda m. \lambda n. n m$
 - Pred: $\lambda n. \lambda f. \lambda x. n (\lambda g. \lambda h. h (g f)) (\lambda n. x) (\lambda n. n)$
 - Succ: $\lambda n. \lambda f. \lambda x. f (n f x)$
 - Less Than / Eq (leq): $\lambda m. \lambda n. c_{isZero} (c_{minus} m n)$
 - Greater Than (ge): $\lambda m. \lambda n. c_{isZero} (c_{minus} n m)$

Boolean Values

- True: $c_{true} = \lambda t. \lambda f. t$
- False: $c_{false} = \lambda t. \lambda f. f$
- And: $c_{and} = \lambda p. \lambda q. p q c_{false}$
- Or: $c_{or} = \lambda p. \lambda q. p c_{true} q$
- Not: $c_{not} = \lambda b. b c_{false} c_{true}$

Pairs

- Pair: $c_{pair} = \lambda a. \lambda b. \lambda f. f a b$
- First: $c_{fst} = \lambda p. p (\lambda a. \lambda b. a)$
- Second: $c_{snd} = \lambda p. p (\lambda a. \lambda b. b)$

Equivalences

α -equivalence

Two terms t_1 and t_2 are α -equivalent $t_1 \stackrel{\alpha}{=} t_2$ if t_1 and t_2 can be transformed into each other just by consistent renaming of the bound variables.

Example

$$\lambda x.x \stackrel{\alpha}{=} \lambda y.y$$

$$\lambda x.(\lambda z.f(\lambda y.zy)x) \stackrel{\alpha}{\neq} \lambda z.(\lambda z.f(\lambda y.z y)z)$$

η -equivalence

Two terms $\lambda x.f x$ and f are η -equivalent $\lambda x.f x \stackrel{\eta}{=} f$ if x is not a free variable of f .

Example

$$\lambda x.f z x \stackrel{\eta}{=} f z$$

$$\lambda x.g x x \stackrel{\eta}{\neq} g x$$

Reductions

β -reduction

A λ -term of the shape $(\lambda x.x) y$ is called a Redex. The β -reduction is the evaluation of a function application on a redex.

$$(\lambda x.t_1) t_2 \Rightarrow t_1 [x \mapsto t_2]$$

Normal Form

A term that can no longer be reduced is called Normal Form. The Normal Form is unique. Terms that don't get reduced to Normal Form diverge (grow infinitely large).

Church-Rosser

The untyped λ is confluent \Leftrightarrow If $t \xrightarrow{*} t_1$ and $t \xrightarrow{*} t_2$ then there exists a t' with $t_1 \xrightarrow{*} t'$ and $t_2 \xrightarrow{*} t'$,

Recursion

For a recursive function $G = \lambda g. (\lambda x. g x)$ has the fixpoint $g^* = Gg^*$ if it exists.

$Y = \lambda f. (\lambda x. f(x)) (\lambda x. f(x))$ is called the recursion operator. $Y G$ is the fixpoint of G .

Example $mod = Y(\lambda mod. \lambda n. \lambda k. (c_{genk})(mod(c_{minusnk})k)n$

Evaluation Strategies

Full β -Reduction Every Redex can be reduced at any time.

Normal Order The leftmost outer redex gets reduced.

Call by Name (CBN) Reduce the leftmost outer Redex if not surrounded by a lambda.

Example

$$(\lambda \textcolor{red}{y}. (\lambda x. \textcolor{red}{y} (\lambda z. z) x)) (\lambda x. x) (\lambda y. y)$$

$$\Rightarrow (\lambda x. ((\lambda \textcolor{red}{x}. \textcolor{red}{x}) (\lambda y. y)) (\lambda z. z) x) \not\Rightarrow$$

Call by Value (CBV) Reduce the leftmost Redex if not surrounded by a lambda and the argument is a value. A value means the term can not be further reduced.

Example

$$(\lambda y. (\lambda x. y (\lambda z. z) x)) ((\lambda \text{green} x. \text{green}) (\lambda \text{red} y. \text{red}))$$

$$\Rightarrow (\lambda \text{green} y. (\lambda x. \text{green} (\lambda z. z) x)) (\lambda \text{red} y. \text{red})$$

$$\Rightarrow (\lambda x. (\lambda \text{green} y. \text{green}) (\lambda \text{red} z. \text{red}) x) \not\Rightarrow$$

Call by Name and Call by Value may not reduce to the Normal Form! Call by Name terminates more often than Call by Value.

Typen

Regelsysteme

- definieren bestimmte Terme als “herleitbar” (geschr. “ $\vdash \psi$ ”)
- Frege’sche Regelnotation: aus dem über dem Strich kann man das unter dem Strich herleiten
- Introduktions- und Eliminationsregeln für und/oder, Quantoren etc. **TODO:** screenshot oder mathtex dafür
- Modus Ponens $\frac{\vdash \psi \Rightarrow \phi \quad \vdash \psi}{\vdash \phi}$
 - Elimination von Implikation
- LEM $\frac{}{\vdash \phi \vee \neg \phi}$
 - (Law of excluded middle)
 - “Es gilt immer ϕ oder $\neg \phi$ ”
- Beweiskontext: $\Gamma \vdash \phi$
 - ϕ unter Annahme von Γ herleitbar
 - Erleichtert Herleitung von $\phi \Rightarrow \psi$
 - Assumption Introduktion $\frac{}{\Gamma, \phi \vdash \phi}$

Typsysteme

- Einfache Typisierung
 - $\vdash (\lambda x. 2) : \text{bool} \rightarrow \text{int}$
 - $\vdash (\lambda x. 2) : \text{int} \rightarrow \text{int}$
 - $\vdash (\lambda f. 2) : (\text{int} \rightarrow \text{int}) \rightarrow \text{int}$
- Polymorphe Typen
 - $\vdash (\lambda x. 2) : \alpha \rightarrow \text{int}$

Regeln

- $\Gamma \vdash t : \tau$: im Typkontext Γ hat Term t den Typ τ
- Γ ordnet freien Variablen x ihren Typ $\Gamma(x)$ zu
- **CONST**

$$\text{CONST} \quad \frac{c \in \text{Const}}{\Gamma \vdash c : \tau_c}$$

- **VAR**

$$\text{VAR} \quad \frac{\Gamma(x) = \tau}{\Gamma \vdash x : \tau}$$

- **ABS**

$$\text{ABS} \quad \frac{\Gamma, x : \tau_1 \vdash t : \tau_2}{\Gamma \vdash \lambda x. t : \tau_1 \rightarrow \tau_2}$$

- **APP**

$$\text{APP} \quad \frac{\Gamma \vdash t_1 : \tau_2 \rightarrow \tau \quad \Gamma \vdash t_2 : \tau_2}{\Gamma \vdash t_1 t_2 : \tau}$$

Forts. Typsysteme

- Nicht alle sicheren Programme sind Typisierbar
 - Typsystem nicht vollständig bzgl. β -Reduktion
 - * insb. Selbsapplikation im Allgemeinen nicht Typisierbar
 - * damit auch nicht Y-Kombinator

Polymorphie

- **Polymorphe Funktionen**
 - Verhalten hängt nicht vom konkreten Typ ab
 - z.B. Operationen auf Containern, wie z.B. Listen

Typschema

- Für $n \in \mathbb{N}$ heißt $\forall \alpha_1 \dots \forall \alpha_n. \tau$ *Typschema* (Kürzel ϕ)
- Es bindet freie Typvariablen $\alpha_1, \dots, \alpha_n$ in τ
- VAR-Regel muss angepasst werden

$$VAR \quad \frac{\Gamma(x) = \phi \quad \phi \succeq \tau}{\Gamma \vdash x : \tau}$$

- LET-Typregel

$$LET \quad \frac{\Gamma \vdash t_1 : \tau_1 \quad \Gamma, x : ta(\tau_1, \Gamma) \vdash t_2 : \tau_2}{\Gamma \vdash let x = t_1 in t_2 : \tau_2}$$

- $ta(\tau, \Gamma)$: Typabstraktion
 - Alle freien Typvariablen von τ quantifiziert, die nicht frei in Typannahmen von Γ
 - \Rightarrow Verhindere Abstraktion von globalen Typvariablen im Schema

Curry-Howard Isomorphism

(constructive logic) proving = (functional) programming

Grundregeln

$$\begin{aligned} \mathbf{fst}\langle M, N \rangle &\rightsquigarrow M \\ \mathbf{snd}\langle M, N \rangle &\rightsquigarrow N \\ (\lambda u.M) N &\rightsquigarrow M[u \mapsto N] \\ \mathbf{case} \mathbf{inl} M \mathbf{of} & \mathbf{inl} u \Rightarrow N \mid \mathbf{inr} w \Rightarrow O \rightsquigarrow N[u \mapsto M] \\ \mathbf{case} \mathbf{inr} M \mathbf{of} & \mathbf{inl} u \Rightarrow N \mid \mathbf{inr} w \Rightarrow O \rightsquigarrow O[w \mapsto M] \end{aligned}$$

Allgemeines Vorgehen

Ziel ist, die Ableitungen auf der linken Seite zu vereinfachen (oder im Fall von η -expansion zu erweitern). Dazu heben sich typischerweise aufeinanderfolgende Operationen der Art Introduction/Destruktion gegenseitig auf.

Justification: reduce elimination of introduction / destructor \circ constructor

β -reduction Beispiel:

$$\frac{\overline{u : A} \quad \mathcal{D} \quad M : B \quad \overline{\mathcal{E}}}{\lambda u. M : A \rightarrow B \quad N : A} \rightsquigarrow \frac{\mathcal{D} \quad \frac{\overline{u : A}}{\mathcal{E}}}{(\lambda u. M) N : B} \quad \rightsquigarrow \quad \frac{\mathcal{D}[u \mapsto N]}{M[u \mapsto N] : B}$$

Unifikation

Unifikator

- Gegeben: Menge C von Gleichungen über Terme
- $\tau = \text{Basistyp}, X = \text{Var}$
- Gesucht ist eine Substitution, die alle Gleichungen erfüllt: **Unifikator**
- **most general unifier**, mgu ist der allgemeinste Unifikator

Definition Unifikator

Substitution σ unifiziert Gleichung $\theta = \theta'$, falls $\sigma\theta = \sigma\theta'$.

σ unifiziert C, falls $\forall c \in C$ gilt: σ unifiziert c.

Bsp. $C = \{f(a, D) = Y, X = g(b), g(Z) = X\} \Rightarrow \sigma = [Y \rightarrow f(a, b), D \rightarrow b, X \rightarrow g(b), Z \rightarrow b]$

Definition mgu

σ mgu, falls \forall Unifikator $\gamma \exists$ Substitution δ . $\gamma = \delta \circ \sigma$.

- Unifikator mit der minimalen Menge an Substitutionen
- Für das Beispiel: $\sigma = [Y \rightarrow f(a, D), X \rightarrow g(b), z \rightarrow b]$
 - für γ z. Bsp. $\delta = [D \rightarrow b]$

Unifikationsalgorithmus: unify(C) =

```

if C == [] then []
else let {θl = θr} ⊔ C' = C in
    if θl == θr then unify(C')
    else if θl == Y and Y ∉ FV(θr) then unify([Y → θr]C') ◦ [Y → θr]
    else if θr == Y and Y ∉ FV(θl) then unify([Y → θl]C') ◦ [Y → θl]
    else if θl == f(θl1, ..., θln) and θr == f(θr1, ..., θrn)
        then unify(C' ∪ {θl1 = θr1, ..., θln = θrn})
    else fail

```

unify(C) terminiert und gibt **mgu** für C zurück, falls C unifizierbar, ansonsten **fail**.

Parallelprogrammierung

Uniform Memory access (UMA): .

Parallelismus: Mindestens zwei Prozesse laufen gleichzeitig.

Concurrency: Mindestens zwei Prozesse machen Fortschritt.

Amdahls' Law:

$$S(n) = \frac{T(1)}{T(n)} = \frac{\text{execution time if processed by 1 processor}}{\text{execution time if processed by n processors}} = \text{speedup}$$

$$S(n) = \frac{1}{(1 - p) + \frac{p}{n}} \text{ with } p = \text{parallelizable percentage of program}$$

Data Parallelism: Die gleiche Aufgabe wird parallel auf unterschiedlichen Daten ausgeführt.

Task Parallelism: Unterschiedliche Aufgaben werden auf den gleichen Daten ausgeführt.

Flynn's Taxanomy

Name	Beschreibung	Beispiel
SISD	a single instruction stream operates on a single memory	von Neumann Architektur
SIMD	one instruction is applied on homogeneous data (e.g. an array)	vector processors of early supercomputer
MIMD	different processors operate on different data	multi-core processors
MISD	multiple instructions are executed simultaneously on the same data	redundant architectures

MPI

```

// default communicator, i.e. the collection of all processes
MPI_Comm MPI_COMM_WORLD;

// returns the number of processing nodes
int MPI_Comm_size(MPI_Comm comm, int *size);

// returns the rank for the processing node, root node has rank 0
int MPI_Comm_rank(MPI_Comm comm, int *rank);

// initializes MPI
int MPI_Init(int *argc, char ***argv);

// Cleans up MPI (called in the end)
int MPI_Finalize();

// blocks until all processes have called it
int MPI_Barrier(MPI_Comm comm);

// blocking asynchronous send. blocks until message buffer can be reused, i.e. message has been received.
int MPI_Send(const void *buf, int count, MPI_Datatype datatype, int dest, int tag, MPI_Comm comm)

// blocking asynchronous receive. blocks until message is received in the buffer completely.
int MPI_Recv(void *buf, int count, MPI_Datatype datatype, int source, int tag,
            MPI_Comm comm, MPI_Status *status)

```

Communication Modes

Synchronous No buffer, synchronization (both sides wait for each other)

Buffered Explicit buffering, no synchronization (no wait for each other)

Ready No buffer, no synchronization, matching receive must already be initiated

Standard May be buffered or not, can be synchronous (implementation dependent)

There is only one receive mode.

```

MPI_Send() // standard-mode blocking send
MPI_Bsend() // buffered-mode blocking send
MPI_Ssend() // synchronous-mode blocking send
MPI_Rsend() // ready-mode blocking send

```

```

// non-blocking send and receive operations
int MPI_Irecv(void *buf, int count, MPI_Datatype datatype, int source,
              int tag, MPI_Comm comm, MPI_Request * request);
int MPI_Isend(const void *buf, int count, MPI_Datatype datatype, int dest, int tag,
              MPI_Comm comm, MPI_Request *request);

// send and receive operations can be checked for completion
int MPI_Test(MPI_Request* r, int* flag, MPI_Status* s);
// blocking check
int MPI_Wait(MPI_Request* r, MPI_Status* s);

```

Collective Operations

MPI_Bcast

```
int MPI_Bcast(void* buffer, int count, MPI_Datatype t, int root, MPI_Comm comm);
```

$$\begin{bmatrix} A_0 \\ \vdots \end{bmatrix} \xrightarrow{\text{Broadcast}} \begin{bmatrix} A_0 \\ A_0 \\ A_0 \end{bmatrix}$$

MPI_Scatter MPI_Gather

```
int MPI_Scatter(const void *sendbuf, int sendcount, MPI_Datatype sendtype,
                void *recvbuf, int recvcount, MPI_Datatype recvtype, int root,
                MPI_Comm comm)
```

```
int MPI_Gather(const void *sendbuf, int sendcount, MPI_Datatype sendtype,
               void *recvbuf, int recvcount, MPI_Datatype recvtype, int root, MPI_Comm comm)
```

$$\begin{bmatrix} A_0 & A_1 & A_2 \end{bmatrix} \xrightleftharpoons[\text{gather}]{\text{scatter}} \begin{bmatrix} A_0 \\ A_1 \\ A_2 \end{bmatrix}$$

MPI_Allgather

```
int MPI_Allgather(const void *sendbuf, int sendcount, MPI_Datatype sendtype,
                  void *recvbuf, int recvcount, MPI_Datatype recvtype, MPI_Comm comm)
```

$$\begin{bmatrix} A_0 \\ B_0 \\ C_0 \end{bmatrix} \xrightarrow{\text{Allgather}} \begin{bmatrix} A_0 & B_0 & C_0 \\ A_0 & B_0 & C_0 \\ A_0 & B_0 & C_0 \end{bmatrix}$$

MPI_Alltoall

```
int MPI_Alltoall(const void *sendbuf, int sendcount, MPI_Datatype sendtype,
                  void *recvbuf, int recvcount, MPI_Datatype recvtype,
                  MPI_Comm comm)
```

$$\begin{bmatrix} A_0 & A_1 & A_2 \\ B_0 & B_1 & B_2 \\ C_0 & C_1 & C_2 \end{bmatrix} \xrightarrow{\text{Alltoall}} \begin{bmatrix} A_0 & B_0 & C_0 \\ A_1 & B_1 & C_1 \\ A_2 & B_2 & C_2 \end{bmatrix}$$

MPI_Reduce

```
int MPI_Reduce(const void *sendbuf, void *recvbuf, int count, MPI_Datatype datatype,
               MPI_Op op, int root, MPI_Comm comm);
```

$$\begin{bmatrix} A_0 & A_1 & A_2 \\ B_0 & B_1 & B_2 \\ C_0 & C_1 & C_2 \end{bmatrix} \xrightarrow{\text{Reduce}} \begin{bmatrix} A_0 + B_0 + C_0 & A_1 + B_1 + C_1 & A_2 + B_2 + C_2 \end{bmatrix}$$

MPI_Allreduce

```
int MPI_Allreduce(const void *sendbuf, void *recvbuf, int count,
                  MPI_Datatype datatype, MPI_Op op, MPI_Comm comm);
```

$$\begin{bmatrix} A_0 & A_1 & A_2 \\ B_0 & B_1 & B_2 \\ C_0 & C_1 & C_2 \end{bmatrix} \xrightarrow{\text{Allreduce}} \begin{bmatrix} A_0 + B_0 + C_0 & A_1 + B_1 + C_1 & A_2 + B_2 + C_2 \\ A_0 + B_0 + C_0 & A_1 + B_1 + C_1 & A_2 + B_2 + C_2 \\ A_0 + B_0 + C_0 & A_1 + B_1 + C_1 & A_2 + B_2 + C_2 \end{bmatrix}$$

MPI_Reduce_scatter

```
int MPI_Reduce_scatter(const void *sendbuf, void *recvbuf, const int recvcounts[],
                       MPI_Datatype datatype, MPI_Op op, MPI_Comm comm)
```

$$\begin{bmatrix} A_0 & A_1 & A_2 \\ B_0 & B_1 & B_2 \\ C_0 & C_1 & C_2 \end{bmatrix} \xrightarrow{\text{Reduce-scatter}} \begin{bmatrix} A_0 + B_0 + C_0 \\ A_1 + B_1 + C_1 \\ A_2 + B_2 + C_2 \end{bmatrix}$$

MPI_Scan

```
int MPI_Scan(const void *sendbuf, void *recvbuf, int count, MPI_Datatype datatype,
             MPI_Op op, MPI_Comm comm);
```

$$\begin{bmatrix} A_0 & A_1 & A_2 \\ B_0 & B_1 & B_2 \\ C_0 & C_1 & C_2 \end{bmatrix} \xrightarrow{\text{Scan}} \begin{bmatrix} A_0 & A_1 & A_2 \\ A_0 + B_0 & A_1 + B_1 & A_2 + B_2 \\ A_0 + B_0 + C_0 & A_1 + B_1 + C_1 & A_2 + B_2 + C_2 \end{bmatrix}$$

Java

Multithreading

Race conditions

A race condition exists if the order in which threads execute their operations influences the result of the program.

Mutual Exclusion A code section, of which only one thread is allowed to execute operations at a time, is called a critical section. If one thread executes operations of a critical section, other threads will be blocked if they want to enter it as well.

```
// Synchronized block, someObject is used as the monitor
synchronized(someObject) {
    ...
}

// synchronized function
synchronized void foo() {
    ...
}
```

Caching and code reordering

- cached variables can lead to inconsistency
- code can be reordered by the compiler

volatile-keyword `volatile` ensures that changes to variables are immediately visible to all threads/processors.

- establishes a happens-before relationship
- values are not locally cached in a CPU cache
- no optimization by compiler

```
// declares a volatile variable
volatile int c = 420;
```

Functional programming

```
// lambdas
(int i, int j) -> i + j;

// functional interfaces
@FunctionalInterface
interface Predicate {
    boolean check(int value);
}

public int sum(List<Integer> values, Predicate predicate) {
    ...
};

sum(values, i -> i > 5);

// method reference to static function
SomeClass::staticFunction;
// method reference to object function
someObject::function;
```

Executors

- Executors abstract from thread creation.
- provides an execute method that accepts a `Runnable`
`void execute(Runnable runnable);`
- `ExecutorService` is an interface that provides further lifecycle management logic

```
Callable<Integer> myCallable = () -> { return currentValue; };
Future<Integer> myFuture = executorService.submit(myCallable);
```

Streams

Provides functions like

- `filter`
- `map, reduce`
- `collect`
- `findAny, findFirst`
- `min, max`

Any Java collection can be treated as a stream by calling the `stream()` method

Example

```
List<Person> personsInAuditorum = ...;
double average =
    personsInAuditorum
```

```

.stream()
.filter(Person::isStudent)
.mapToInt(Person::getAge) // converts a regular Stream to IntStream
.average()
.getAsDouble();

// collector
R collect(
    Supplier<R> supplier,
    BiConsumer<R, ? super T> accumulator,
    BiConsumer<R, R> combiner // only used for parallel streams
);

personsInAuditorium.stream().collect(
    () -> 0,
    (currentSum, person) -> { currentSum += person.getAge(); },
    (leftSum, rightSum) -> { leftSum += rightSum; }
);

// parallel stream
someValues.parallelStream();

```

Design by Contract

Form of a Hoare triple $\{P\} C \{Q\}$

- P : precondition → specification what the supplier expects from the client
- C : series of statements → the method of body
- Q : postcondition → specification of what the client can expect from the supplier if the precondition is fulfilled
- client has to ensure that the precondition is fulfilled
- client can expect the postcondition to be fulfilled, if the precondition is
- **Non-Redundancy-Principle:** the body of a routine shall not test for the routine's precondition

```

/*@ requires size > 0;
 @ ensures size == \old(size) - 1;
 @ ensures \result == \old{top()};
 @ ensures true; // trivial constraint
 */
Object pop() { ... }

```

Liskov Substitution Principle

- preconditions must not be more restrictive than those of the overwritten method: $\text{Precondition}_{\text{Super}} \Rightarrow \text{Precondition}_{\text{Sub}}$
- postcondition must be at least as restrictive as those of the overwritten methods: $\text{Postcondition}_{\text{Sub}} \Rightarrow \text{Postcondition}_{\text{Super}}$

Compiler

Basics

- **Lexikalische Analyse:**
 - Eingabe: Sequenz von Zeichen
 - Aufgaben:

- * erkenne bedeutungstragende Zeichengruppen: Tokens
- * überspringe unwichtige Zeichen (Leerzeichen, Kommentare, ...)
- * bezeichner identifizieren und zusammenfassen in Stringtabelle
- Ausgabe: Sequenz von Tokens
- **Syntaktische Analyse:**
 - Eingabe: Sequenz von Tokens
 - Aufgaben:
 - * überprüfe, ob Eingabe zu kontextfreier Sprache gehört
 - * erkenne hierachische Struktur der Eingabe
 - Ausgabe: Abstrakter Syntaxbaum (AST)
- **Semantische Analyse:**
 - Eingabe: Syntax Baum
 - Aufgaben: kontextsensitive Analyse (syntaktische Analyse ist kontextfrei)
 - * Namensanalyse: Beziehung zwischen Deklaration und Verwendung
 - * Typanalyse: Bestimme und prüfe Typen von Variablen, Funktionen, ...
 - * Konsistenzprüfung: Alle Einschränkungen der Programmiersprache eingehalten
 - Ausgabe: Attributierter Syntaxbaum
 - ungültige Programme werden spätestens in Semantischer Analyse abgelehnt
- **Codegerierung:**
 - Eingabe: Attributierter Syntaxbaum oder Zwischencode
 - Aufgaben: Erzeuge Code für Zielmaschine
 - Ausgabe: Program in Assembler oder Maschinencode

Linksrekursion

- Linksrekursive kontextfreie Grammatiken sind für kein k SLL(k).
- Für jede kontextfreie Grammatik G mit linksrekursiven Produktionen gibt es eine kontextfreie Grammatik G' ohne Linksrekursion mit $L(G) = L(G')$

Java Bytecode

General

```
; this list partly is stolen from some guy on discord, but I forgot which one
; types
i -> int
l -> long
s -> short
b -> byte
c -> char
f -> float
d -> double
a -> reference

; load constants on the stack
acconst_null ; null object
dconst_0 ; double 0
dconst_1 ; double 1
fconst_0 ... fconst_2 ; float 0 to 2
iconst_0 ... iconst_5 ; integer 0 to 5

; push immediates
bipush i ; push signed byte i on the stack
sipush i ; push signed short i on the stack

; variables (X should be replaced by a type, for example i (integer))
; there exists Xload_i for i in [0, 3] to save a few bytes
```

```

Xload i ; load local variable i (is a number)
Xstore i ; store local variable i

; return from function
return ; void return
Xreturn ; return value of type X

; conditional jumps
if_icmpeq label ; jump if ints are equal
if_icmpge label ; jump if first int is >=
if_icmpgt label ; jump if first int is >
if_icmple label ; jump if first int is <=
if_icmplt label ; jump if first int is <

ifeq label ; jump if = zero
ifge label ; jump if >= zero
ifgt label ; jump if > zero
iflt label ; jump if < zero
ifle label ; jump if <= zero
ifne label ; jump if != zero

ifnull label ; jump if null
ifnonnull label ; jump if not null

; Arithmetic, always operates on stack
; push left side first, then right side
iinc var const ; increment variable var (number) by const (immediate)
isub ; Integer subtraction, for stack top -> [1,2,3] it would be 2 - 1
iadd ; Integer addition
imul ; Integer multiplication
idiv ; Integer division
ineg ; negate int
ishl ; shift left (arith)
ishr ; shift right (arith)

; Logic (für [i, l])
iand ; Bitwise and
ior ; Bitwise or
ixor ; Bitwise or

; Method calls. Stack: [objref, arg1, arg2] <-
invokevirtual #desc ; call method specified in desc
invokespecial #desc ; call constructor
invokeinterface #desc ; call method on interface
invokestatic #desc ; call static method (no objref)

; Misc
nop ; No operation

; Arrays
newarray T ; new array of type T
Xaload ; load type X from array [Stack: arr, index] <-
Xastore ; store type X in array [Stack: arr, index, val] <-
arraylength ; length of array

```

Examples

Arithmetic Java:

```
void calc(int x, int y) {  
    int z = 4;  
    z = y * z + x;  
}
```

Bytecode:

```
iconst_4 // lege eine 4 auf den stack  
istore_3 // pop stack und speichere Wert in Variable 3 (z)  
iload_2 // lade Variable 2 (y) und lege sie auf den stack  
iload_3 // lade Variable 3 (z) und lege sie auf den stack  
imul // multipliziere die oberen zwei elemente und lege das ergebnis auf den stack (y * z)  
iload_1 // lade Variable 1 (x) und lege sie auf den Stack  
iadd // addiere die oberen zwei Elemente und lege sie auf den stack  
istore_1 // pop stack und speichere Wert in Variable 3 (z)
```

Loops Java:

```
public int fib(int steps) {  
    int last0 = 1;  
    int last1 = 1;  
    while (--steps > 0) {  
        int t = last0 + last1;  
        last1 = last0;  
        last0 = t;  
    }  
}
```

Bytecode:

```
iconst_1 // put 1 on stack  
istore_2 // store top of stack in var 2  
iconst_1 // put 1 on stack  
istore_3 // store top of stack in var 3  
  
loop_begin: // label  
iinc 1 -1 // increment var 1 by -1  
iload_1 // load var 1 and put on stack  
ifle after_loop // if top of stack <= 0, jump to after_loop  
iload_2 // put var 2 on stack  
iload_3 // put var 3 on stack  
iadd // add top two elements and put on stack  
istore 4 // store top of stack in var 4  
iload_2 // load var 2 and put on stack  
istore_3 // store top of stack in var 3  
iload 4 // load var 4 and put on stack  
istore_2 // store top of stack in var 2  
goto loop_begin // jump to loop_begin  
after_loop: // label  
iload_2 // load var 2 and put on stack  
ireturn // return top of stack
```