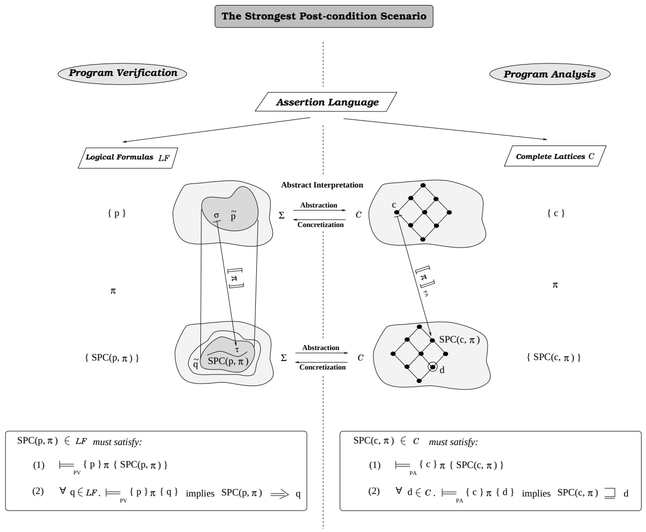
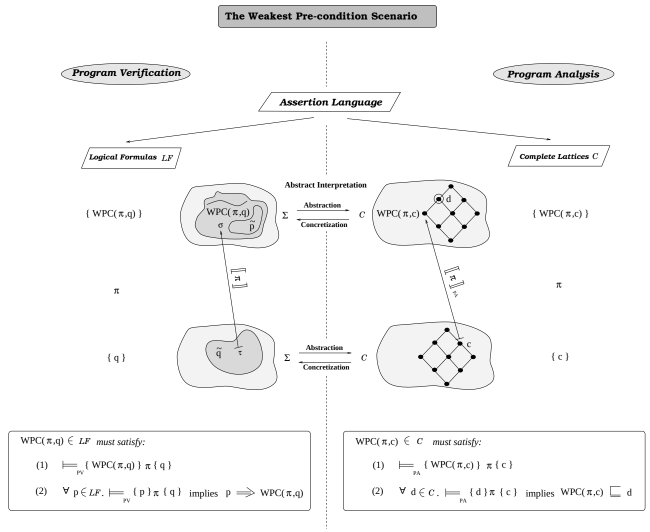
Programmverifikation vs. -analyse (1)



Programmverifikation vs. -analyse (2)



Reverse abstrakte Semantik

Reverse abstrakte Semantik

1. *Datenflussanalyseverband* $\widehat{\mathcal{C}} = (\mathcal{C}, \sqcap, \sqcup, \sqsubseteq, \bot, \top)$
2. *Reverses Datenflussanalysefunktional* $[\![\ ]\!]_R : E \to (\mathcal{C} \to \mathcal{C})$ definiert durch

$$\forall\, e \in E\ \forall\, c \in \mathcal{C}.\ [\![\, e \,]\!]_R(c) =_{df} \bigsqcap \{\, c' \mid [\![\, e \,]\!](c') \sqsupseteq c \,\}$$

wobei $[\![\ ]\!] : E \to (\mathcal{C} \to \mathcal{C})$ eine abstrakte Semantik auf $\mathcal{C}$ ist.

Zusammenhang von $[\![\ ]\!]$ und $[\![\ ]\!]_R$ (1)

Lemma

Sei $[\![\ ]\!]$ ein Datenflussanalysefunktional. Dann gilt für jede Kante $e \in E$:

1. $[\![\, e \,]\!]_R$ ist wohldefiniert und monoton.
2. $[\![\, e \,]\!]_R$ ist additiv, falls $[\![\, e \,]\!]$ distributiv ist.

Zusammenhang von $[\![\ ]\!]$ und $[\![\ ]\!]_R$ (2)

Lemma

Sei $[\![\ ]\!]$ ein Datenflussanalysefunktional. Dann gilt für jede Kante $e \in E$:

1. $[\![\, e\,]\!]_R \circ [\![\, e\,]\!] \sqsubseteq Id_{\mathcal{C}}$, falls $[\![\, e\,]\!]$ monoton ist.
2. $[\![\, e\,]\!] \circ [\![\, e\,]\!]_R \sqsupseteq Id_{\mathcal{C}}$, falls $[\![\, e\,]\!]$ distributiv ist.

Sprechweise in der Theorie "Abstrakter Interpretation":

- $[\![\, e\,]\!]$ und $[\![\, e\,]\!]_R$ bilden eine Galois-Verbindung.

Zusammenhang von $[\![\ ]\!]$ und $[\![\ ]\!]_R$ (3)

Hilfssatz

1. $\forall\, n \in N' \cap N.\ \mathbf{P}_{G'}[\mathbf{s}, n] = \mathbf{P}_G[\mathbf{s}, n]$
2. $\forall\, q \in N' \backslash \{\mathbf{s}\}.\ \mathbf{P}_{G'}[\mathbf{s}, q] = \mathbf{P}_G[\mathbf{s}, \mathbf{q}]$
3. $\forall\, c_{\mathbf{s}} \in \mathcal{C}\ \forall\, n \in N' \cap N.\ MOP_{(G', c_{\mathbf{s}})}(n) = MOP_{(G, c_{\mathbf{s}})}(n)$
4. $MOP_{(G, c_{\mathbf{s}})}(q) = MOP_{(G, c_{\mathbf{s}})}(\mathbf{q})$

Der *R-JOP*-Ansatz

Die *R-JOP*-Lösung:

$$\forall\, c_q \in \mathcal{C}\ \forall\, n \in N.\ R\text{-}JOP_{c_q}(n) =_{df} \bigsqcup \{\, [\![\, p\,]\!]_R(c_q) \mid p \in \mathbf{P}[n, \mathbf{q}]\,\}$$

Der *R-MinFP*-Ansatz

Das *R-MinFP*-Gleichungssystem:

$$\textbf{reqInf}\ (n) = \begin{cases} c_q & \text{falls } n = \mathbf{q} \\ \bigsqcup \{\, [\![\, (n,m)\,]\!]_R(\textbf{reqInf}\ (m)) \mid m \in succ(n)\,\} & \text{sonst} \end{cases}$$

Bezeichne $\textbf{reqInf}^*_{c_q}$ die kleinste Lösung dieses Gleichungssystems bzgl. $c_q \in \mathcal{C}$.

Die *R-MinFP*-Lösung:

$$\forall\, c_q \in \mathcal{C}\ \forall\, n \in N.\ R\text{-}MinFP_{c_q}(n) =_{df} \textbf{reqInf}\ ^*_{c_q}(n)$$

Der generische R-$MinFP$-Alg. (1)

Input: (1) A flow graph $G = (N, E, \mathbf{s}, \mathbf{e})$, (2) a program point q, (3) a reverse abstract semantics (i.e., a data-flow lattice $\mathcal{C}$, and a reverse data-flow functional $[\![\ ]\!]_R : E \to (\mathcal{C} \to \mathcal{C})$ induced by a functional $[\![\ ]\!] : E \to (\mathcal{C} \to \mathcal{C})$), and (4) a component information $c_q \in \mathcal{C}$.

Output: Under the assumption of termination (cf. Theorem **??**), the R-$MinFP$-solution. Depending on the properties of the underlying reverse data-flow functional, this has the following interpretation.

(1) $[\![\ ]\!]_R$ *is additive:* Variable *reqInf*[$\mathbf{s}$] stores the weakest context information of c_q, i.e., the least data-flow fact which must be ensured at the program entry in order to guarantee c_q at q. If this is $\top$, the requested component information cannot be satisfied at all.

(2) $[\![\ ]\!]_R$ *is monotonic:* Variable *reqInf*[$\mathbf{s}$] stores a lower bound of the weakest context candidate of c_q. Generally, this is not a sufficient context information itself. Hence, except for the special case *reqInf*[$\mathbf{s}$] $= \top$, which implies that c_q cannot be satisfied by any consistent context information, nothing can be concluded from the value of *reqInf*[$\mathbf{s}$].

Remark: The variable *workset* controls the iterative process. Its elements are nodes of G, whose informations annotating them have recently been updated.

Der generische R-$MinFP$-Alg. (2)

(Prologue: Initialization of the annotation array *reqInf*, and the variable *workset*)

FORALL $n \in N \backslash \{\mathbf{q}\}$ DO *reqInf*[n] $:= \bot$ OD;
reqInf[$\mathbf{q}$] $:= c_q$;
workset $:= \{\mathbf{q}\}$;

Der generische R-$MinFP$-Alg. (3)

(Main process: Iterative fixed point computation)

```
WHILE workset ≠ ∅ DO
  CHOOSE m ∈ workset;
   workset := workset\{m};
   ( Update the predecessor-environment of node m )
   FORALL n ∈ pred(m) DO
    join := [[ (n,m) ]]_R(reqInf[m]) ⊔ reqInf[n];
    IF reqInf[n] ⊏ join
     THEN
      reqInf[n] := join;
      workset := workset ∪ {n}
    FI
   OD
  ESOOHC
OD.
```


Reverses Sicherheitstheorem

Reverses Sicherheitstheorem

Die R-$MinFP$-Lösung ist eine obere (d.h. sichere) Approximation der R-JOP-Lösung, d.h.,

$$\forall\, c_q \in \mathcal{C}\ \forall\, n \in N.\ R\text{-}MinFP_{c_q}(n) \sqsupseteq R\text{-}JOP_{c_q}(n)$$

Reverses Koinzidenztheorem

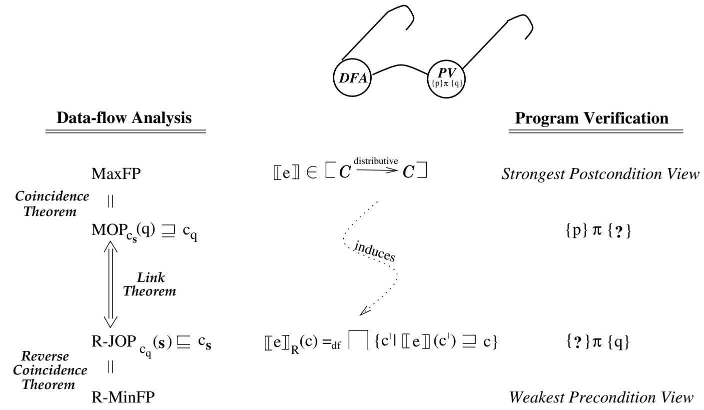
Reverses Koinzidenztheorem

Diee $R\text{-}MinFP$-Lösung stimmt mit der $R\text{-}JOP$-Lösung überein, d.h.,

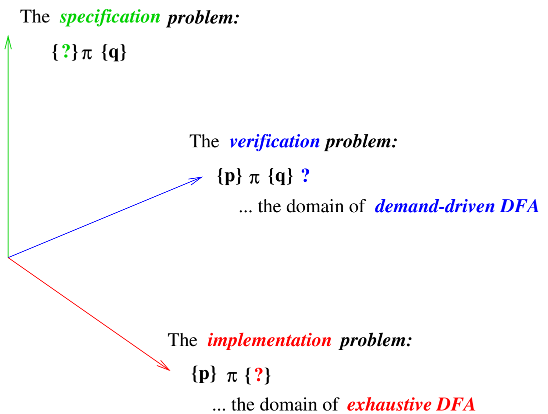
$$\forall\, c_q \in \mathcal{C}\ \forall\, n \in N.\ R\text{-}MinFP_{c_q}(n) = R\text{-}JOP_{c_q}(n)$$

falls $[\![\ ]\!]$ distributiv ist.

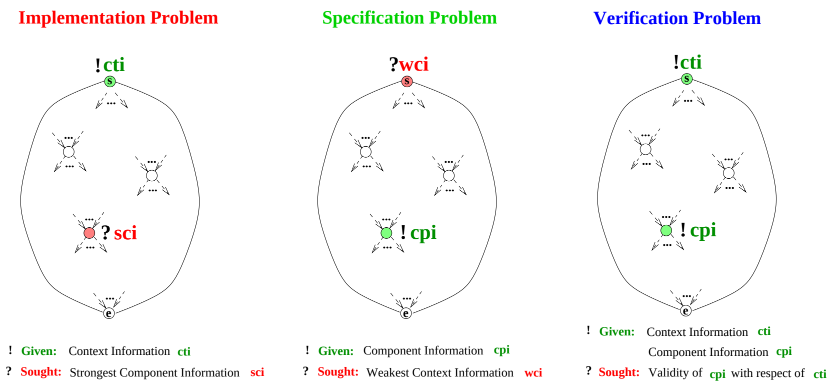
DFA vs. Verifikation: Überblick



Drei unterschiedliche Problemperspektiven (1)

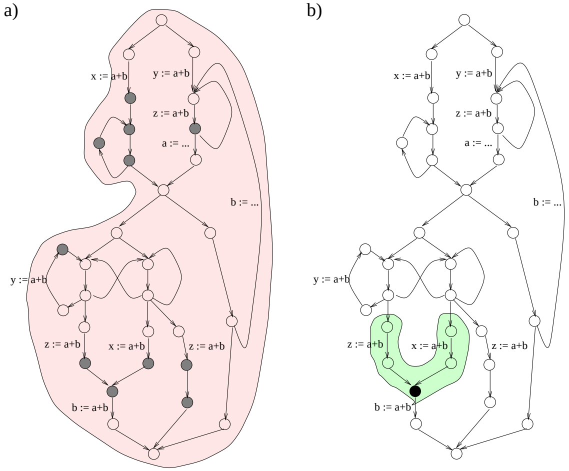


Drei unterschiedliche Problemperspektiven (2)



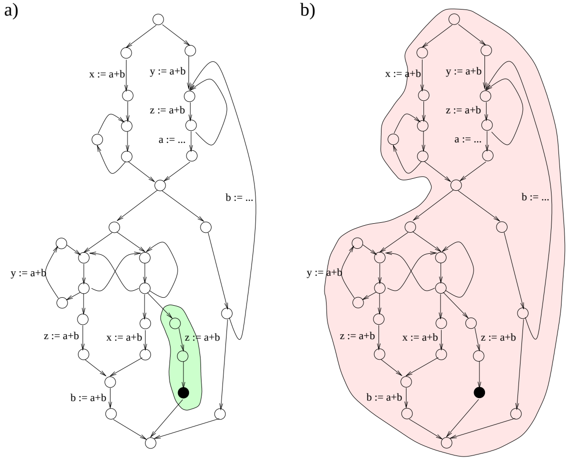
Bsp: Verfügbarkeit an einem Punkt (1)

a) b)



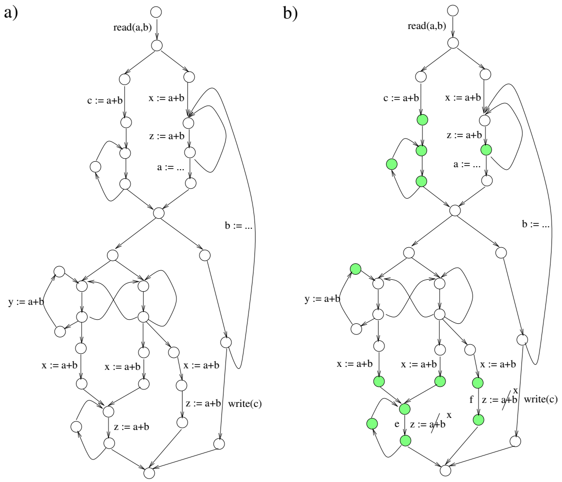
Bsp: Verfügbarkeit an einem Punkt (2)

a) b)



Anwendung: Einfacher Optimierer (1)

a) b)



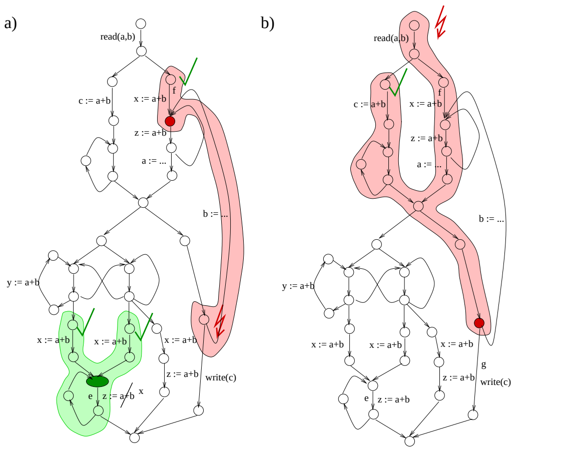
Flow graph

Data-flow information

Program points satisfying **availability**

Anwendung: "Hot Spot" Optimierer und Debugger (2)

a) b)



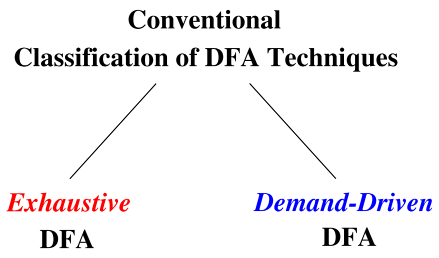
"Hot Spot" Optimizer

Program point satisfies **availability**, while does not!

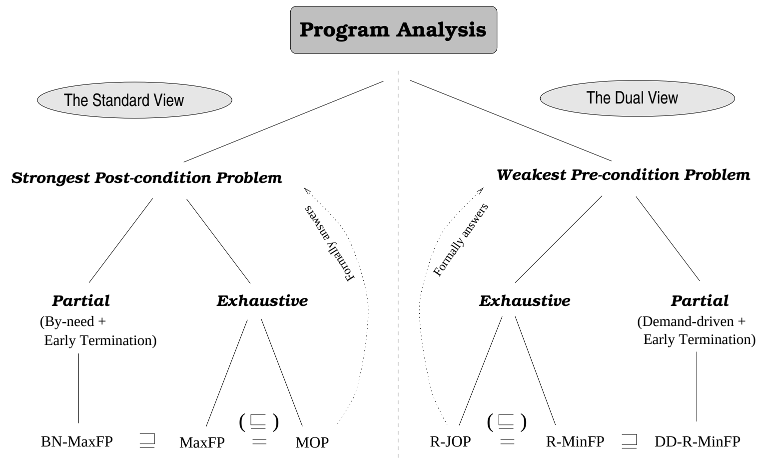
Debugger

Variable c is not initialized along some paths reaching program point

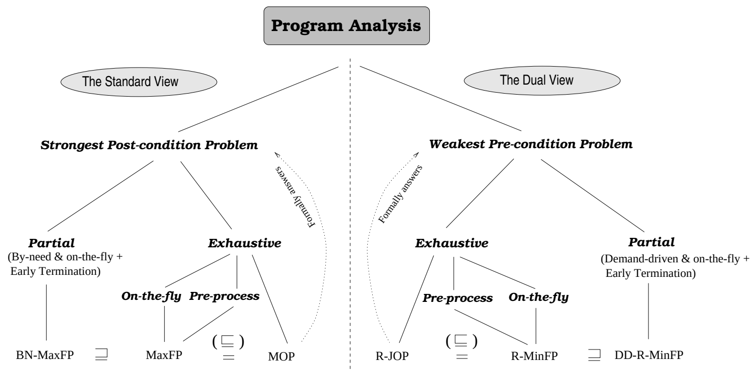
Erschöpfende vs. anforderungsgetriebe-ne DFA (1)



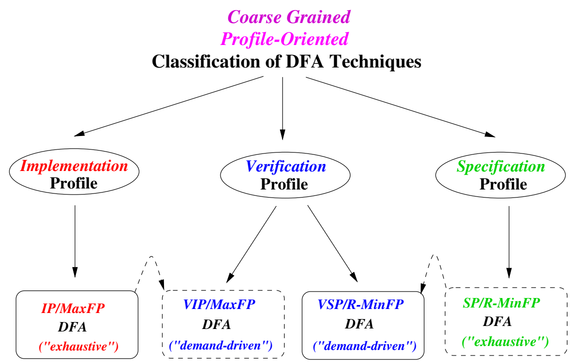
Erschöpfende vs. anforderungsgetriebe-ne DFA (2)



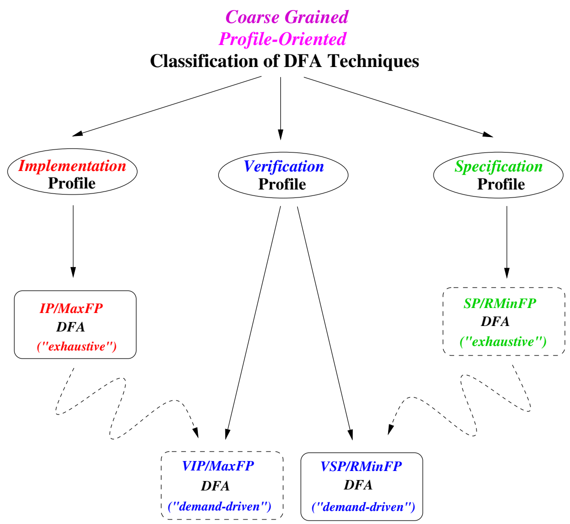
Erschöpfende vs. anforderungsgetriebe-ne DFA (3)



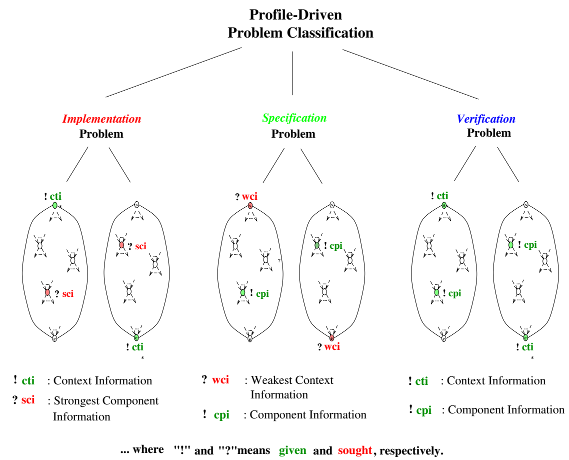
Eine andere Sicht (1)



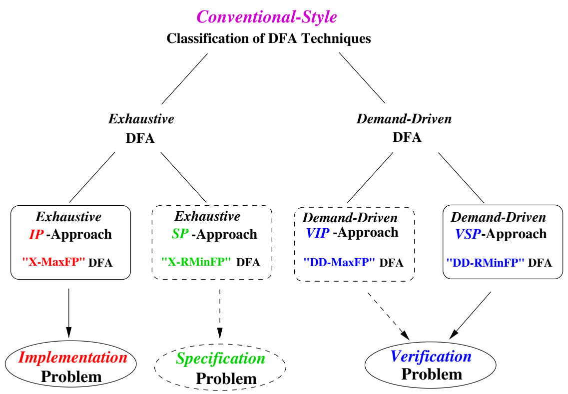
Eine andere Sicht (2)



Im Überblick



Zum Abschluss: Algorithmenorientiert (1)



Zum Abschluss: Problemorientiert (2)