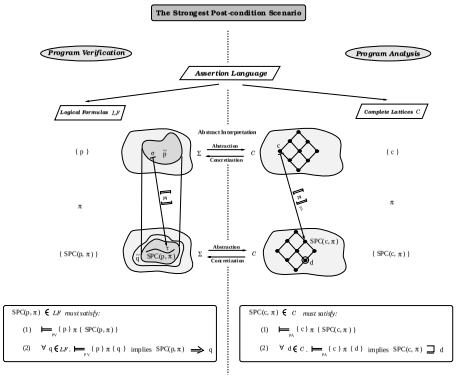
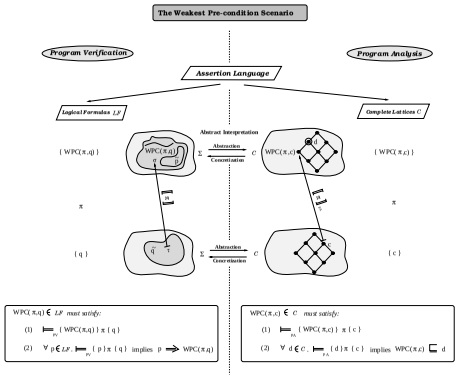
Programmverifikation vs. -analyse (1)



Programmverifikation vs. -analyse (2)



Reverse abstrakte Semantik

Reverse abstrakte Semantik

1. *Datenflussanalyseverband* $\hat{\mathcal{C}} = (\mathcal{C}, \sqcap, \sqcup, \sqsubseteq, \bot, \top)$
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*[**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*[**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*[**s**] $= \top$, which implies that c_q cannot be satisfied by any consistent context information, nothing can be concluded from the value of *reqInf*[**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*[**q**] $:= \bot$ OD;
reqInf[**q**] $:= c_q$;
workset $:= \{\mathbf{q}\}$;

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

(Main process: Iterative fixed point computation)

WHILE *workset* $\neq \emptyset$ DO
  CHOOSE $m \in$ *workset*;
    workset $:=$ *workset*$\backslash\{m\}$;
    (Update the predecessor-environment of node m)
    FORALL $n \in pred(m)$ DO
      join $:= [\![(n, m)]\!]_R$(*reqInf*[m]) $\sqcup$ *reqInf*[n];
      IF *reqInf*[n] $\sqsubset$ *join*
        THEN
          reqInf[n] $:=$ *join*;
          workset $:=$ *workset* $\cup \{n\}$
      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

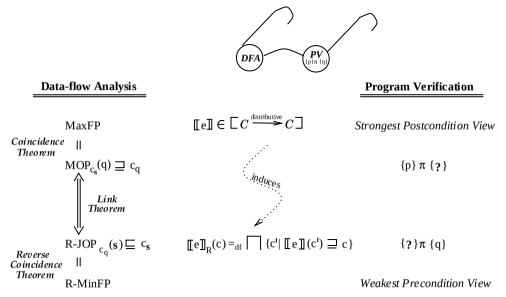
Reverses Koinzidenztheorem

Diee R-$MinFP$-Lösung stimmt mit der R-JOP-Lösung überein, d.h.,

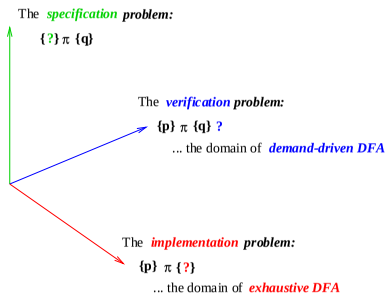
$$\forall\, c_q \in \mathcal{C}\ \forall\, n \in N.\ R\text{-}MinFP_{c_q}(n) = R\text{-}JOP_{c_q}(n)$$

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

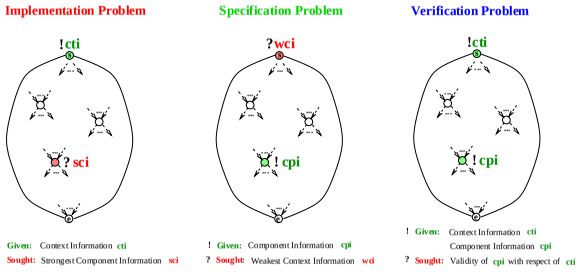
DFA vs. Verifikation: Überblick



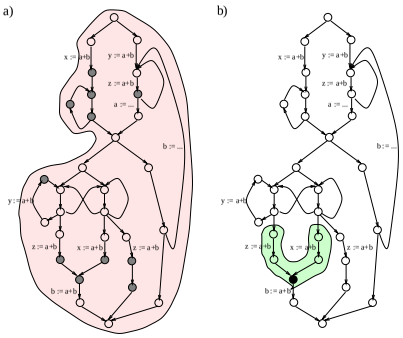
Drei unterschiedliche Problemperspektiven (1)



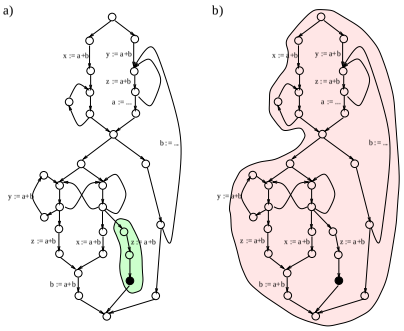
Drei unterschiedliche Problemperspektiven (2)



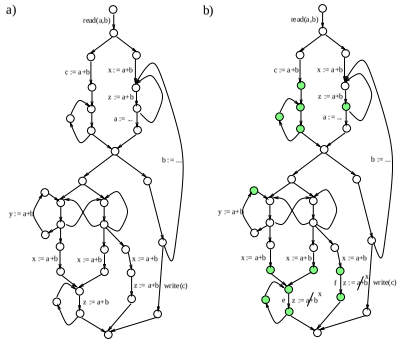
Bsp: Verfügbarkeit an einem Punkt (1)



Bsp: Verfügbarkeit an einem Punkt (2)



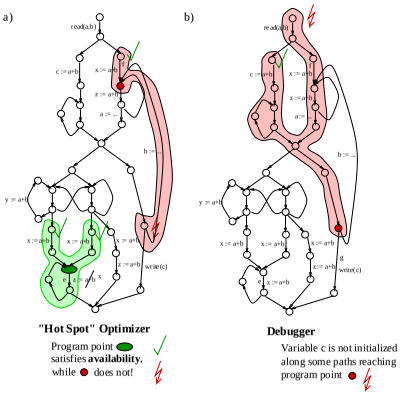
Anwendung: Einfacher Optimierer (1)



Flow graph

Data-flow information
Program points
satisfying **availability**

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



"Hot Spot" Optimizer
Program point satisfies **availability**, while does not!

Debugger
Variable c is not initialized along some paths reaching program point

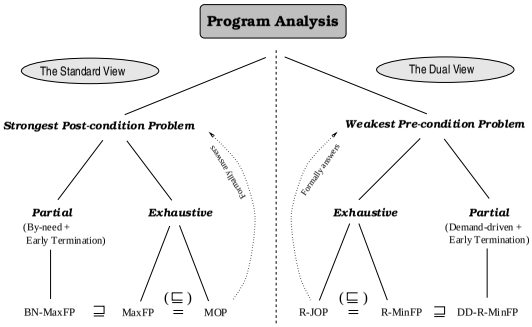
Erschöpfende vs. anforderungsgetriebene DFA (1)

Conventional
Classification of DFA Techniques

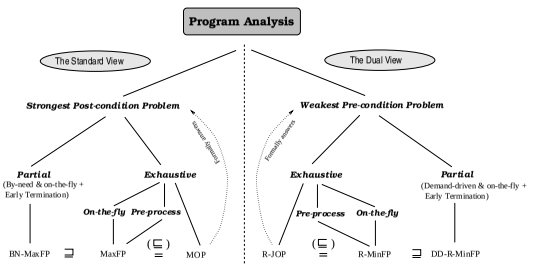
Exhaustive **DFA**

Demand-Driven **DFA**

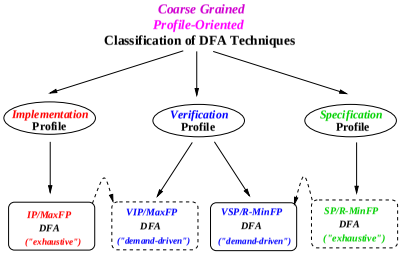
Erschöpfende vs. anforderungsgetriebene DFA (2)



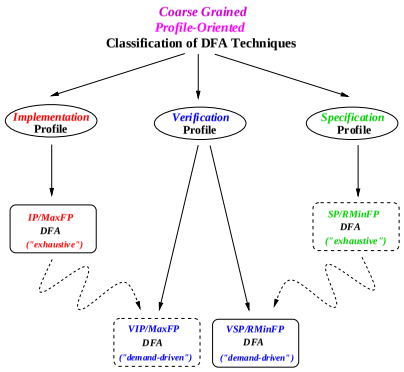
Erschöpfende vs. anforderungsgetriebene DFA (3)



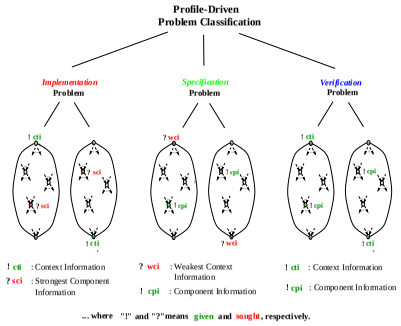
Eine andere Sicht (1)



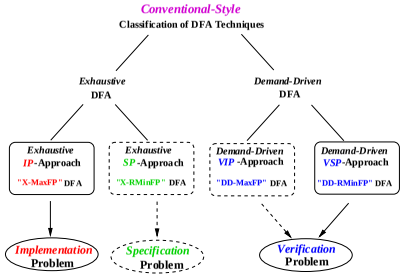
Eine andere Sicht (2)



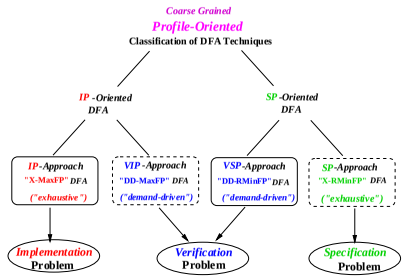
Im Überblick



Zum Abschluss: Algorithmenorientiert (1)



Zum Abschluss: Problemorientiert (2)



Vorschau auf die weiteren Vorlesungstermine...

- Mo, 21.01.2008: Vorlesung von 16:15 Uhr bis 17:45 Uhr im Hörsaal 14, TU-Hauptgebäude