Semantic Solutions to Program Analysis Problems

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A talk in three parts.

1. A provocative claim. (The thought)
2. A idea about modular program analysis. (The idea)
3. And a demo! (The fun)

The claim

Program analysis should focus on semantics

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Program analysis should focus on semantics
instead of focusing on abstraction.

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$\longrightarrow$ Interesting Semantics $\longrightarrow$ Computable Analysis

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Program analysis should focus on semantics instead of focusing on abstraction.

$\longrightarrow$ Interesting Semantics $\longrightarrow$ Computable Analysis

Three reasons

Why focus on semantics?

1. Semantics is easier to get right
2. Off-the-shelf approximation techniques exist
3. Semantics by itself is interesting

Getting it wrong

$$
\begin{aligned}
((\lambda x^{\beta}.e)^{\ell_\lambda}\ v^{\ell_v})^{\ell_a} &\longrightarrow e[v^{\ell_v}/x^{\beta}] \\
(n^{\ell_n}\ v^{\ell_v})^{\ell_a} &\longrightarrow (\text{blame}\ \lambda\ \mathcal{R})^{\ell_a} \\
(\text{if0}\ 0^{\ell_0}\ e_1\ e_2)^{\ell} &\longrightarrow e_1 \\
(\text{if0}\ v^{\ell_v}\ e_1\ e_2)^{\ell} &\longrightarrow e_2 \\
(\text{int}^{\ell\ell'}_{f} \Leftarrow n^{\ell_n})^{\ell_c} &\longrightarrow n^{\ell} \\
(\text{int}^{\ell\ell'}_{f} \Leftarrow \vec{v}^{\ell_v})^{\ell_c} &\longrightarrow (\text{blame}\ f\ \mathcal{R})^{\ell'} \\
((c_1 \to c_2)^{\ell\ell'}_{f} \Leftarrow \vec{v}^{\ell_v})^{\ell_c} &\longrightarrow ((c_1 \hat{\to} c_2)^{\ell\ell'}_{f} \Leftarrow \vec{v}^{\ell_v})^{\ell_c} \\
((c_1 \to c_2)^{\ell\ell'}_{f} \Leftarrow n^{\ell_n})^{\ell_c} &\longrightarrow (\text{blame}\ f\ \mathcal{R})^{\ell'} \\
(((c_1 \hat{\to} c_2)^{\ell\ell'}_{f} \Leftarrow \vec{v}^{\ell_v})^{\ell_c}\ w^{\ell_w})^{\ell_a} &\longrightarrow (c_2 \Leftarrow (\vec{v}^{\ell_v}\ (c_1 \Leftarrow w^{\ell_w})^{\mathcal{L}^+(c_1)})^{\mathcal{L}^-(c_2)})^{\mathcal{L}^+(c_2)}
\end{aligned}
$$

Getting it wrong

$Source \setminus Sink$	$\mathrm{int}_h^{\ell_5^+\ell_5^-}$
n^{ℓ_n}	
$\mathrm{int}_f^{\ell_1^+\ell_1^-}$	
$(\lambda x^\beta.e^\ell)^{\ell_\lambda}$	$\{\ell_\lambda\}\subseteq\varphi(\ell_5^-) \Rightarrow \{\langle h,\mathcal{R}\rangle\}\subseteq\psi(\ell_5^-)$
$(c_g^{\ell_1^+\ell_1^-}\to c_f^{\ell_2^+\ell_2^-})_f^{\ell_3^+\ell_3^-}$	$\{\ell_3^+\}\subseteq\varphi(\ell_5^-) \Rightarrow \{\langle h,\mathcal{R}\rangle\}\subseteq\psi(\ell_5^-)$

$Source \setminus Sink$	$(e^{\ell_5}\ e^{\ell_6})^{\ell_a}$	$(c_i^{\ell_7^+\ell_7^-}\to c_h^{\ell_8^+\ell_8^-})_h^{\ell_5^+\ell_5^-}$
n^{ℓ_n}	$\{\ell_n\}\subseteq\varphi(\ell_5) \Rightarrow \{\langle\lambda,\mathcal{R}\rangle\}\subseteq\psi(\ell_a)$	$\{\ell_n\}\subseteq\varphi(\ell_5^-) \Rightarrow \{\langle h,\mathcal{R}\rangle\}\subseteq\psi(\ell_5^-)$
$\mathrm{int}_f^{\ell_1^+\ell_1^-}$	$\{\ell_1^+\}\subseteq\varphi(\ell_5) \Rightarrow \{\langle\lambda,\mathcal{R}\rangle\}\subseteq\psi(\ell_a)$	$\{\ell_1^+\}\subseteq\varphi(\ell_5^-) \Rightarrow \{\langle h,\mathcal{R}\rangle\}\subseteq\psi(\ell_5^-)$
$(\lambda x^\beta.e^\ell)^{\ell_\lambda}$	$\{\ell_\lambda\}\subseteq\varphi(\ell_5) \Rightarrow \varphi(\ell_6)\subseteq\varphi(\beta)$ $\{\ell_\lambda\}\subseteq\varphi(\ell_5) \Rightarrow \varphi(\ell)\subseteq\varphi(\ell_a)$	$\{\ell_\lambda\}\subseteq\varphi(\ell_5^-) \Rightarrow \varphi(\ell_7^+)\subseteq\varphi(\beta)$ $\{\ell_\lambda\}\subseteq\varphi(\ell_5^-) \Rightarrow \varphi(\ell)\subseteq\varphi(\ell_8^-)$
$(c_g^{\ell_1^+\ell_1^-}\to c_f^{\ell_2^+\ell_2^-})_f^{\ell_3^+\ell_3^-}$	$\{\ell_3^+\}\subseteq\varphi(\ell_5) \Rightarrow \varphi(\ell_6)\subseteq\varphi(\ell_1^-)$ $\{\ell_3^+\}\subseteq\varphi(\ell_5) \Rightarrow \varphi(\ell_2^+)\subseteq\varphi(\ell_a)$	$\{\ell_3^+\}\subseteq\varphi(\ell_5^-) \Rightarrow \varphi(\ell_7^+)\subseteq\varphi(\ell_1^-)$ $\{\ell_3^+\}\subseteq\varphi(\ell_5^-) \Rightarrow \varphi(\ell_2^+)\subseteq\varphi(\ell_8^-)$

Getting it wrong

Source╲*Sink*	$\mathsf{int}_h^{\ell_5^+\ell_5^-}$	$\langle \dots e_5\ \mathsf{int}_h^{\ell_5^+\ell_5^-}\rangle_h^{\ell_6^+\ell_6^-}$	$\mathsf{any}_h^{\ell_5^+\ell_5^-}$	$\langle \dots e_5\ \mathsf{any}_h^{\ell_5^+\ell_5^-}\rangle_h^{\ell_6^+\ell_6^-}$
$n_{e_1\dots}^{\ell_n}$		$\{\ell_n\}\subseteq\varphi(\ell_5^-)$, $e_1\dots\not\sqsubseteq e_5$ $\Rightarrow \{\langle h,\mathcal{O}\rangle\}\subseteq\psi(\ell_5^-)$		$\{\ell_n\}\subseteq\varphi(\ell_5^-)$, $e_1\dots\not\sqsubseteq e_5$ $\Rightarrow \{\langle h,\mathcal{O}\rangle\}\subseteq\psi(\ell_5^-)$
$\mathsf{int}_f^{\ell_1^+\ell_1^-}$		$\{\ell_1^+\}\subseteq\varphi(\ell_5^-) \Rightarrow \{\langle h,\mathcal{O}\rangle\}\subseteq\psi(\ell_5^-)$		$\{\ell_1^+\}\subseteq\varphi(\ell_5^-) \Rightarrow \{\langle h,\mathcal{O}\rangle\}\subseteq\psi(\ell_5^-)$
$\langle\dots e_1\ \mathsf{int}_f^{\ell_1^+\ell_1^-}\rangle_f^{\ell_2^+\ell_2^-}$		$\{\ell_1^+\}\subseteq\varphi(\ell_5^-)$, $e_1\not\sqsubseteq e_5$ $\Rightarrow \{\langle h,\mathcal{O}\rangle\}\subseteq\psi(\ell_5^-)$		$\{\ell_1^+\}\subseteq\varphi(\ell_5^-)$, $e_1\not\sqsubseteq e_5$ $\Rightarrow \{\langle h,\mathcal{O}\rangle\}\subseteq\psi(\ell_5^-)$
$\mathsf{any}_f^{\ell_1^+\ell_1^-}$	$\{\ell_1^+\}\subseteq\varphi(\ell_5^-) \Rightarrow \{\langle h,\mathcal{R}\rangle\}\subseteq\psi(\ell_5^-)$			$\{\ell_1^+\}\subseteq\varphi(\ell_5^-) \Rightarrow \{\langle h,\mathcal{O}\rangle\}\subseteq\psi(\ell_5^-)$
$\langle\dots e_1\ \mathsf{any}_f^{\ell_1^+\ell_1^-}\rangle_f^{\ell_2^+\ell_2^-}$				$\{\ell_1^+\}\subseteq\varphi(\ell_5^-)$, $e_1\not\sqsubseteq e_5$ $\Rightarrow \{\langle h,\mathcal{O}\rangle\}\subseteq\psi(\ell_5^-)$
$(\lambda x^\beta.e^\ell)_{e_1\dots}^{\ell_\lambda}$	$\{\ell_\lambda\}\subseteq\varphi(\ell_5^-) \Rightarrow \{\langle h,\mathcal{R}\rangle\}\subseteq\psi(\ell_5^-)$		$\{\ell_\lambda\}\subseteq\varphi(\ell_5^-) \Rightarrow \varphi(\ell_5^+)\subseteq\varphi(\beta)$ $\{\ell_\lambda\}\subseteq\varphi(\ell_5^-) \Rightarrow \varphi(\ell)\subseteq\varphi(\ell_5^-)$	$\{\ell_\lambda\}\subseteq\varphi(\ell_5^-)$, $e_1\dots\not\sqsubseteq e_5$ $\Rightarrow \{\langle h,\mathcal{O}\rangle\}\subseteq\psi(\ell_5^-)$
$(c_g^{\ell_1^+\ell_1^-}\to c_f^{\ell_2^+\ell_2^-})_f^{\ell_3^+\ell_3^-}$	$\{\ell_3^+\}\subseteq\varphi(\ell_5^-) \Rightarrow \{\langle h,\mathcal{R}\rangle\}\subseteq\psi(\ell_5^-)$		$\{\ell_3^+\}\subseteq\varphi(\ell_5^-) \Rightarrow \varphi(\ell_5^+)\subseteq\varphi(\ell_1^-)$ $\{\ell_3^+\}\subseteq\varphi(\ell_5^-) \Rightarrow \varphi(\ell_2^+)\subseteq\varphi(\ell_5^-)$	$\{\ell_3^+\}\subseteq\varphi(\ell_5^-) \Rightarrow \{\langle h,\mathcal{O}\rangle\}\subseteq\psi(\ell_5^-)$
$\langle\dots e_3\ (c_g^{\ell_1^+\ell_1^-}\to c_f^{\ell_2^+\ell_2^-})_f^{\ell_3^+\ell_3^-}\rangle_f^{\ell_4^+\ell_4^-}$				$\{\ell_3^+\}\subseteq\varphi(\ell_5^-)$, $e_3\not\sqsubseteq e_5$ $\Rightarrow \{\langle h,\mathcal{O}\rangle\}\subseteq\psi(\ell_5^-)$

Source╲*Sink*	$(e^{\ell_5}\ e^{\ell_6})^{\ell_a}$	$(c_i^{\ell_7^+\ell_7^-}\to c_h^{\ell_8^+\ell_8^-})_h^{\ell_5^+\ell_5^-}$	$\langle\dots e_5\ (c_i^{\ell_7^+\ell_7^-}\to c_h^{\ell_8^+\ell_8^-})_h^{\ell_5^+\ell_5^-}\rangle_h^{\ell_6^+\ell_6^-}$
$n_{e_1\dots}^{\ell_n}$	$\{\ell_n\}\subseteq\varphi(\ell_5) \Rightarrow \{\langle\lambda,\mathcal{R}\rangle\}\subseteq\psi(\ell_a)$	$\{\ell_n\}\subseteq\varphi(\ell_5^-) \Rightarrow \{\langle h,\mathcal{R}\rangle\}\subseteq\psi(\ell_5^-)$	
$\mathsf{int}_f^{\ell_1^+\ell_1^-}$	$\{\ell_1^+\}\subseteq\varphi(\ell_5) \Rightarrow \{\langle\lambda,\mathcal{R}\rangle\}\subseteq\psi(\ell_a)$	$\{\ell_1^+\}\subseteq\varphi(\ell_5^-) \Rightarrow \{\langle h,\mathcal{R}\rangle\}\subseteq\psi(\ell_5^-)$	
$\langle\dots e_1\ \mathsf{int}_f^{\ell_1^+\ell_1^-}\rangle_f^{\ell_2^+\ell_2^-}$			
$\mathsf{any}_f^{\ell_1^+\ell_1^-}$			
$\langle\dots e_1\ \mathsf{any}_f^{\ell_1^+\ell_1^-}\rangle_f^{\ell_2^+\ell_2^-}$			
$(\lambda x^\beta.e^\ell)_{e_1\dots}^{\ell_\lambda}$	$\{\ell_\lambda\}\subseteq\varphi(\ell_5) \Rightarrow \varphi(\ell_6)\subseteq\varphi(\beta)$ $\{\ell_\lambda\}\subseteq\varphi(\ell_5) \Rightarrow \varphi(\ell)\subseteq\varphi(\ell_a)$	$\{\ell_\lambda\}\subseteq\varphi(\ell_5^-) \Rightarrow \varphi(\ell_7^+)\subseteq\varphi(\beta)$ $\{\ell_\lambda\}\subseteq\varphi(\ell_5^-) \Rightarrow \varphi(\ell)\subseteq\varphi(\ell_8^-)$	$\{\ell_\lambda\}\subseteq\varphi(\ell_5^-)$, $e_1\dots\not\sqsubseteq e_5$ $\Rightarrow \{\langle h,\mathcal{O}\rangle\}\subseteq\psi(\ell_5^-)$
$(c_g^{\ell_1^+\ell_1^-}\to c_f^{\ell_2^+\ell_2^-})_f^{\ell_3^+\ell_3^-}$	$\{\ell_3^+\}\subseteq\varphi(\ell_5) \Rightarrow \varphi(\ell_6)\subseteq\varphi(\ell_1^-)$ $\{\ell_3^+\}\subseteq\varphi(\ell_5) \Rightarrow \varphi(\ell_2^+)\subseteq\varphi(\ell_a)$	$\{\ell_3^+\}\subseteq\varphi(\ell_5^-) \Rightarrow \varphi(\ell_7^+)\subseteq\varphi(\ell_1^-)$ $\{\ell_3^+\}\subseteq\varphi(\ell_5^-) \Rightarrow \varphi(\ell_2^+)\subseteq\varphi(\ell_8^-)$	$\{\ell_3^+\}\subseteq\varphi(\ell_5^-) \Rightarrow \{\langle h,\mathcal{O}\rangle\}\subseteq\psi(\ell_5^-)$
$\langle\dots e_3\ (c_g^{\ell_1^+\ell_1^-}\to c_f^{\ell_2^+\ell_2^-})_f^{\ell_3^+\ell_3^-}\rangle_f^{\ell_4^+\ell_4^-}$			$\{\ell_3^+\}\subseteq\varphi(\ell_5^-)$, $e_3\not\sqsubseteq e_5$ $\Rightarrow \{\langle h,\mathcal{O}\rangle\}\subseteq\psi(\ell_5^-)$

Table 1. Constraints creation for source-sink pairs.

Getting it wrong

Source$\diagdown$*Sink*	$\text{int}_h^{\ell_5^+\ell_5^-}$	$\langle\ldots e_5\ \text{int}_h^{\ell_5^+\ell_5^-}\rangle_h^{\ell_6^+\ell_6^-}$	$\text{any}_h^{\ell_5^+\ell_5^-}$	$\langle\ldots e_5\ \text{any}_h^{\ell_5^+\ell_5^-}\rangle_h^{\ell_6^+\ell_6^-}$
$n_{e_1\ldots}^{\ell_n}$		$\left.\begin{matrix}\{\ell_n\}\subseteq\varphi(\ell_5^-)\\ e_1\ldots\not\sqsubseteq e_5\end{matrix}\right\}\Rightarrow\{\langle h,\mathcal{O}\rangle\}\subseteq\psi(\ell_5^-)$		$\left.\begin{matrix}\{\ell_n\}\subseteq\varphi(\ell_5^-)\\ e_1\ldots\not\sqsubseteq e_5\end{matrix}\right\}\Rightarrow\{\langle h,\mathcal{O}\rangle\}\subseteq\psi(\ell_5^-)$
$\text{int}_f^{\ell_1^+\ell_1^-}$		$\{\ell_1^+\}\subseteq\varphi(\ell_5^-)\Rightarrow\{\langle h,\mathcal{O}\rangle\}\subseteq\psi(\ell_5^-)$		$\{\ell_1^+\}\subseteq\varphi(\ell_5^-)\Rightarrow\{\langle h,\mathcal{O}\rangle\}\subseteq\psi(\ell_5^-)$
$\langle\ldots e_1\ \text{int}_f^{\ell_1^+\ell_1^-}\rangle_f^{\ell_2^+\ell_2^-}$		$\left.\begin{matrix}\{\ell_1^+\}\subseteq\varphi(\ell_5^-)\\ e_1\not\sqsubseteq e_5\end{matrix}\right\}\Rightarrow\{\langle h,\mathcal{O}\rangle\}\subseteq\psi(\ell_5^-)$		$\left.\begin{matrix}\{\ell_1^+\}\subseteq\varphi(\ell_5^-)\\ e_1\not\sqsubseteq e_5\end{matrix}\right\}\Rightarrow\{\langle h,\mathcal{O}\rangle\}\subseteq\psi(\ell_5^-)$
$\text{any}_f^{\ell_1^+\ell_1^-}$	$\{\ell_1^+\}\subseteq\varphi(\ell_5^-)\Rightarrow\{\langle h,\mathcal{R}\rangle\}\subseteq\psi(\ell_5^-)$			$\{\ell_1^+\}\subseteq\varphi(\ell_5^-)\Rightarrow\{\langle h,\mathcal{O}\rangle\}\subseteq\psi(\ell_5^-)$
$\langle\ldots e_1\ \text{any}_f^{\ell_1^+\ell_1^-}\rangle_f^{\ell_2^+\ell_2^-}$				$\left.\begin{matrix}\{\ell_1^+\}\subseteq\varphi(\ell_5^-)\\ e_1\not\sqsubseteq e_5\end{matrix}\right\}\Rightarrow\{\langle h,\mathcal{O}\rangle\}\subseteq\psi(\ell_5^-)$
$(\lambda x^\beta.e^\ell)_{e_1\ldots}^{\ell_\lambda}$	$\{\ell_\lambda\}\subseteq\varphi(\ell_5^-)\Rightarrow\{\langle h,\mathcal{R}\rangle\}\subseteq\psi(\ell_5^-)$		$\{\ell_\lambda\}\subseteq\varphi(\ell_5^-)\Rightarrow\varphi(\ell_5^+)\subseteq\varphi(\beta)$ $\{\ell_\lambda\}\subseteq\varphi(\ell_5^-)\Rightarrow\varphi(\ell)\subseteq\varphi(\ell_5^-)$	$\left.\begin{matrix}\{\ell_\lambda\}\subseteq\varphi(\ell_5^-)\\ e_1\ldots\not\sqsubseteq e_5\end{matrix}\right\}\Rightarrow\{\langle h,\mathcal{O}\rangle\}\subseteq\psi(\ell_5^-)$
$(c_g^{\ell_1^+\ell_1^-}\to c_f^{\ell_2^+\ell_2^-})_f^{\ell_3^+\ell_3^-}$	$\{\ell_3^+\}\subseteq\varphi(\ell_5^-)\Rightarrow\{\langle h,\mathcal{R}\rangle\}\subseteq\psi(\ell_5^-)$		$\{\ell_3^+\}\subseteq\varphi(\ell_5^-)\Rightarrow\varphi(\ell_5^+)\subseteq\varphi(\ell_1^-)$ $\{\ell_3^+\}\subseteq\varphi(\ell_5^-)\Rightarrow\varphi(\ell_2^+)\subseteq\varphi(\ell_5^-)$	$\{\ell_3^+\}\subseteq\varphi(\ell_5^-)\Rightarrow\{\langle h,\mathcal{O}\rangle\}\subseteq\psi(\ell_5^-)$
$\langle\ldots e_3\ (c_g^{\ell_1^+\ell_1^-}\to c_f^{\ell_2^+\ell_2^-})_f^{\ell_3^+\ell_3^-}\rangle_f^{\ell_4^+\ell_4^-}$				$\left.\begin{matrix}\{\ell_3^+\}\subseteq\varphi(\ell_5^-)\\ e_3\not\sqsubseteq e_5\end{matrix}\right\}\Rightarrow\{\langle h,\mathcal{O}\rangle\}\subseteq\psi(\ell_5^-)$

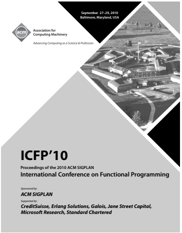
Source$\diagdown$*Sink*	$(e^{\ell_5}\ e^{\ell_6})^{\ell_a}$	$(c_i^{\ell_7^+\ell_7^-}\to c_h^{\ell_8^+\ell_8^-})_h^{\ell_5^+\ell_5^-}$	$\langle\ldots e_5\ (c_i^{\ell_7^+\ell_7^-}\to c_h^{\ell_8^+\ell_8^-})_h^{\ell_5^+\ell_5^-}\rangle_h^{\ell_6^+\ell_6^-}$
$n_{e_1\ldots}^{\ell_n}$	$\{\ell_n\}\subseteq\varphi(\ell_5)\Rightarrow\{\langle\lambda,\mathcal{R}\rangle\}\subseteq\psi(\ell_a)$	$\{\ell_n\}\subseteq\varphi(\ell_5^-)\Rightarrow\{\langle h,\mathcal{R}\rangle\}\subseteq\psi(\ell_5^-)$	
$\text{int}_f^{\ell_1^+\ell_1^-}$	$\{\ell_1^+\}\subseteq\varphi(\ell_5)\Rightarrow\{\langle\lambda,\mathcal{R}\rangle\}\subseteq\psi(\ell_a)$	$\{\ell_1^+\}\subseteq\varphi(\ell_5^-)\Rightarrow\{\langle h,\mathcal{R}\rangle\}\subseteq\psi(\ell_5^-)$	
$\langle\ldots e_1\ \text{int}_f^{\ell_1^+\ell_1^-}\rangle_f^{\ell_2^+\ell_2^-}$			
$\text{any}_f^{\ell_1^+\ell_1^-}$			
$\langle\ldots e_1\ \text{any}_f^{\ell_1^+\ell_1^-}\rangle_f^{\ell_2^+\ell_2^-}$			
$(\lambda x^\beta.e^\ell)_{e_1\ldots}^{\ell_\lambda}$	$\{\ell_\lambda\}\subseteq\varphi(\ell_5)\Rightarrow\varphi(\ell_6)\subseteq\varphi(\beta)$ $\{\ell_\lambda\}\subseteq\varphi(\ell_5)\Rightarrow\varphi(\ell)\subseteq\varphi(\ell_a)$	$\{\ell_\lambda\}\subseteq\varphi(\ell_5^-)\Rightarrow\varphi(\ell_7^+)\subseteq\varphi(\beta)$ $\{\ell_\lambda\}\subseteq\varphi(\ell_5^-)\Rightarrow\varphi(\ell)\subseteq\varphi(\ell_8^-)$	$\left.\begin{matrix}\{\ell_\lambda\}\subseteq\varphi(\ell_5^-)\\ e_1\ldots\not\sqsubseteq e_5\end{matrix}\right\}\Rightarrow\{\langle h,\mathcal{O}\rangle\}\subseteq\psi(\ell_5^-)$
$(c_g^{\ell_1^+\ell_1^-}\to c_f^{\ell_2^+\ell_2^-})_f^{\ell_3^+\ell_3^-}$	$\{\ell_3^+\}\subseteq\varphi(\ell_5)\Rightarrow\varphi(\ell_6)\subseteq\varphi(\ell_1^-)$ $\{\ell_3^+\}\subseteq\varphi(\ell_5)\Rightarrow\varphi(\ell_2^+)\subseteq\varphi(\ell_a)$	$\{\ell_3^+\}\subseteq\varphi(\ell_5^-)\Rightarrow\varphi(\ell_7^+)\subseteq\varphi(\ell_1^-)$ $\{\ell_3^+\}\subseteq\varphi(\ell_5^-)\Rightarrow\varphi(\ell_2^+)\subseteq\varphi(\ell_8^-)$	$\{\ell_3^+\}\subseteq\varphi(\ell_5^-)\Rightarrow\{\langle h,\mathcal{O}\rangle\}\subseteq\psi(\ell_5^-)$
$\langle\ldots e_3\ (c_g^{\ell_1^+\ell_1^-}\to c_f^{\ell_2^+\ell_2^-})_f^{\ell_3^+\ell_3^-}\rangle_f^{\ell_4^+\ell_4^-}$			$\left.\begin{matrix}\{\ell_3^+\}\subseteq\varphi(\ell_5^-)\\ e_3\not\sqsubseteq e_5\end{matrix}\right\}\Rightarrow\{\langle h,\mathcal{O}\rangle\}\subseteq\psi(\ell_5^-)$

Table 1. Constraints creation for source-sink pairs.

The shelf

Generic abstraction techniques exist.

- Nielsen, Nielsen, and Hankin, '99
- Cousot, '02
- Van Horn and Might, '10: Abstracting Abstract Machines



Semantics as verification

Once you have a semantics that answers interesting questions, try running it.

A Modular Semantics

Modularity matters.

Modularity of analysis matters.

Modularity matters.

- Some programs are open (c.f.: the web).

```
// dynamically load any javascript file.
load.getScript = function(filename) {
  var script = document.createElement('script')
  script.setAttribute("type","text/javascript")
  script.setAttribute("src", filename)
  if (typeof script!="undefined")
  document.getElementsByTagName("head")[0]
          .appendChild(script)
}
```

Modularity matters.

- Good components are written in bad languages.

```
#include "escheme.h"
Scheme_Object *scheme_initialize(Scheme_Env *env) {
  Scheme_Env *mod_env;
  mod_env = scheme_primitive_module(scheme_intern_symbol("hi"),
                                    env);
  scheme_add_global("greeting",
                    scheme_make_utf8_string("hello"),
                    mod_env);
  scheme_finish_primitive_module(mod_env);
  return scheme_void;
}

Scheme_Object *scheme_reload(Scheme_Env *env) {
  return scheme_initialize(env); /* Nothing special for reload */
}

Scheme_Object *scheme_module_name() {
  return scheme_intern_symbol("hi");
}
```

Modularity matters.

- Libraries matter.

```
;; To use: (require (planet dvanhorn/ralist))
;; Purely Functional Random-Access Lists.
;; Implementation based on Okasaki, FPCA '95.
#lang racket
(provide (all-defined-out))

(struct tree        (val))
(struct (leaf tree) ())
(struct (node tree) (left right))

;; X [RaListof X] -> [RaListof X]
(define (ra:cons x ls)
 (match ls
   [(list-rest (cons s t1) (cons s t2) r)
    (cons (cons (+ 1 s s) (make-node x t1 t2)) r)]
   [else
    (cons (cons 1 (make-leaf x)) ls)]))
...
```

An idea:

reduction semantics + abstract values
= *abstract* reduction semantics

An idea:

reduction semantics + abstract values
= *abstract* reduction semantics

$$(\lambda x.E)\ V \quad \triangleright \quad \{V/x\}E$$

An idea:

reduction semantics + abstract values
= *abstract* reduction semantics

$$\frac{(\lambda x.E)\ V \quad \triangleright \quad \{V/x\}E \qquad (\lambda x.E) \quad : \quad A \rightarrow B}{}$$

An idea:

reduction semantics + abstract values
= *abstract* reduction semantics

$$\frac{\begin{array}{rcl}(\lambda x.E)\ V & \rhd & \{V/x\}E \\ (\lambda x.E) & : & A \to B\end{array}}{\begin{array}{rcl}(A \to B)\ V & \blacktriangleright & B\end{array}}$$

```
(module fact (int/c -> int/c)
  (lambda (x)
    (if (= x 0)
        1
        (* x (fact (sub1 x))))))

(module input int/c 0)

(fact input)
```

$\triangleright^*$ `((lambda (x) ...) 0)`

$\triangleright^*$ `1`

```
(module fact (int/c -> int/c)
   •)
```

```
(module input int/c 0)

(fact input)

▶* ((int/c -> int/c) 0)
▶* int/c
```

```
(module fact (int/c -> int/c)
  (lambda (x)
    (if (= x 0)
        1
        (* x (fact (sub1 x))))))

(module input int/c •)

(fact input)
```

►* ((lambda (x) ...) int/c) ►* (if (= int/c 0) 0 ...)
►* (if bool 1 ...)
►* 1, int/c

```
(module * (int/c int/c -> int/c) •)
(module sub1 (int/c -> int/c) •)
(module fact (int/c -> int/c)
  (lambda (x)
    (if (= x 0)
        1
        (* x (fact (sub1 x))))))

(module input int/c 0)

(fact input)

▶* ((lambda (x) ...) 0)
▶* 1
```

```
(module * (int/c int/c -> int/c) •)
(module sub1 (int/c -> int/c) •)
(module fact (int/c -> int/c)
  (lambda (x)
    (if (= x 0)
        1
        (* x (fact (sub1 x))))))

(module input int/c •)

(fact input)

▶* ((lambda (x) ...) int/c)
▶* int/c
```

```
(module * (any/c any/c -> int/c) •)
(module sub1 (any/c -> int/c) •)
(module fact any/c
  (lambda (x)
    (if (= x 0)
        1
        (* x (fact (sub1 x))))))

(module input int/c •)

(fact input)

▶* ((lambda (x) ...) int/c)
▶* int/c
```

Demo

- Focus on semantics.
- Abstract reduction provides modularity.
- A semantics can be a verifier.

`http://bit.ly/abstract-reduction`
`http://redex.racket-lang.org`