Compilation of OCaml memory model to Power

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An execution result is explained by alternating threads… usually

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C++ allows it due to a (non-atomic) data race

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Standard for Programming Language C++, 6.8.2.1.20:
"Any such data race results in undefined behavior."

No races on atomics

$[x] = [y] = 0$		
$[x]^{rlx} := 1$	$a := [x]^{rlx}$	$b := [y]^{rlx}$
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Constants

Defined in header <atomic>

Value
`memory_order_relaxed`

No races on atomics but the outcome is still allowed

$[x] = [y] = 0$		
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$$= \{ \ldots, (a=b=c=1), \ldots (a=b=1, c=0), \ldots \}$$

C++ memory model is **weak**

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C++ memory model is **weak** as it allows optimizations

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Weak behavior can be controlled with access modes

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Weak behavior can be controlled with access modes but the effect is not obvious

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POWER

C++ solution: strengthen access mode everywhere

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OCaml MM: reasonable rules for racy programs

$[x] = [y] = 0$		
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OCaml MM guarantees should be implemented

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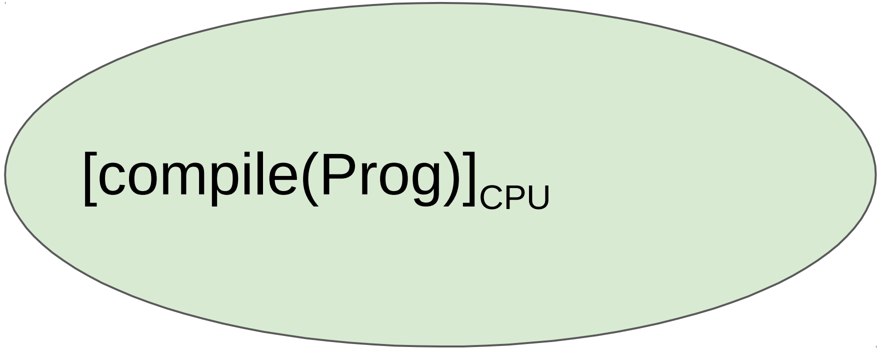
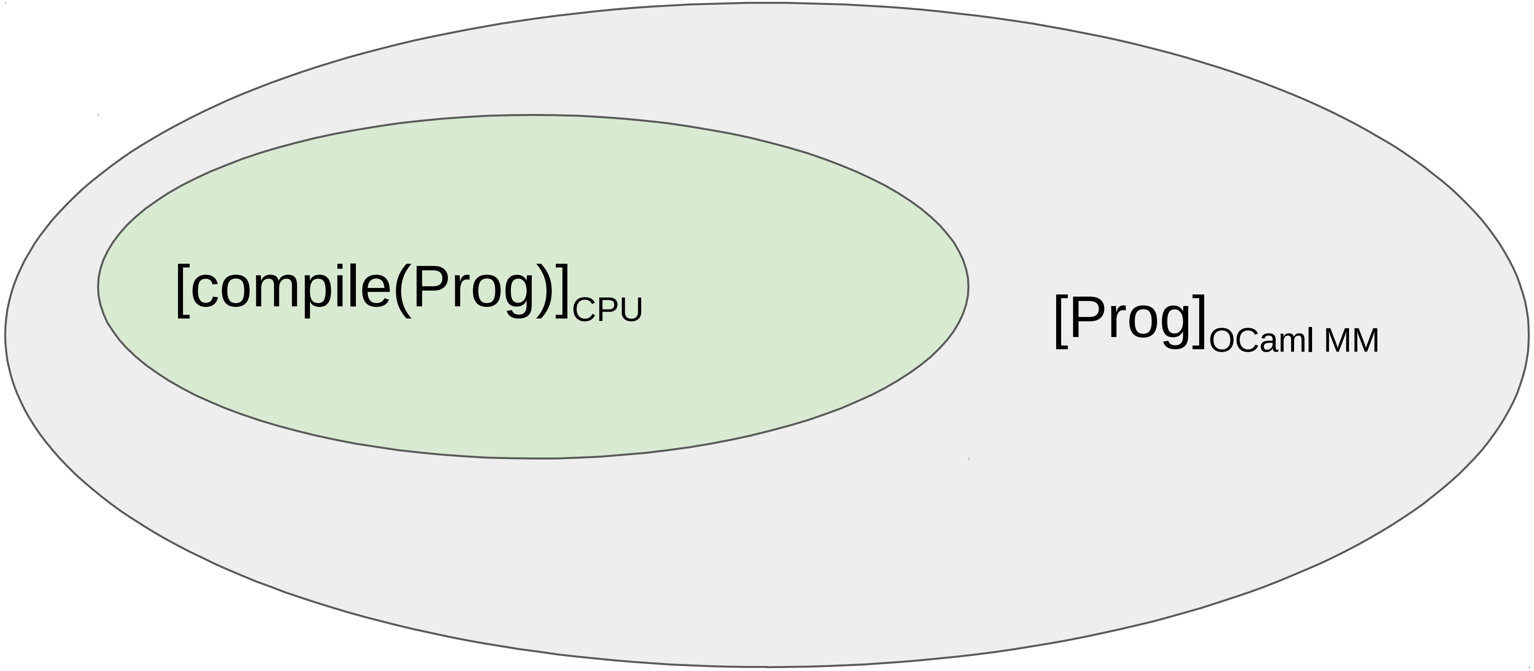
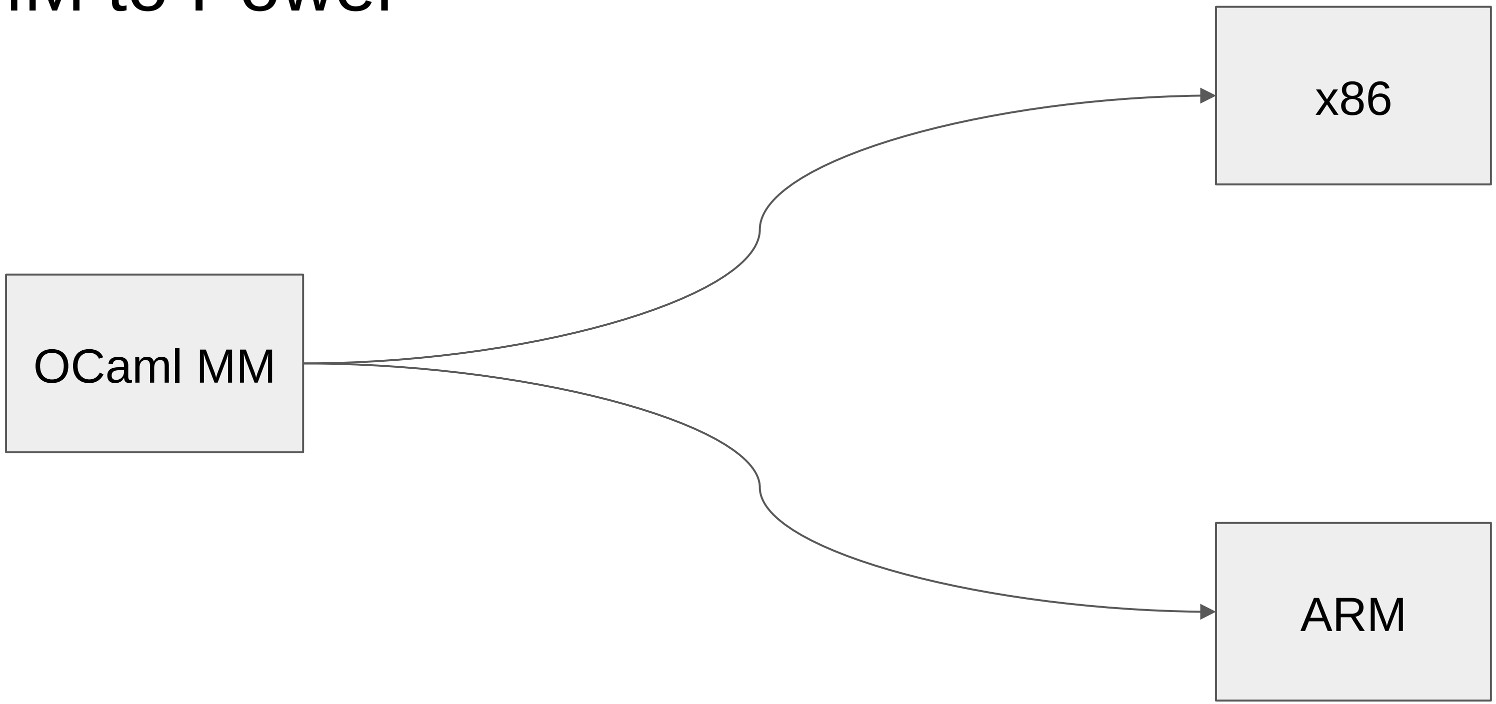


OCaml MM guarantees should be implemented by providing a correct compilation scheme



We’ve proved compilation correctness from OCaml MM to Power



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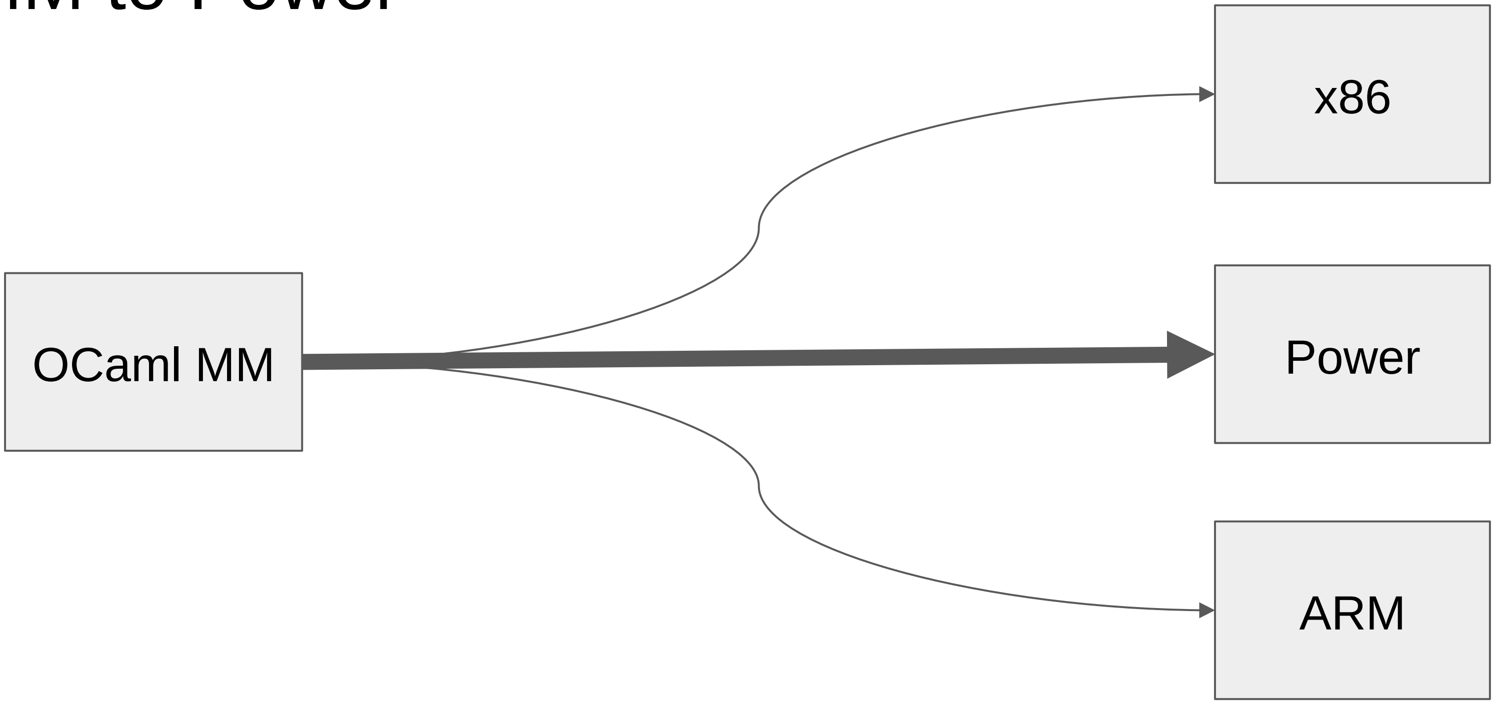
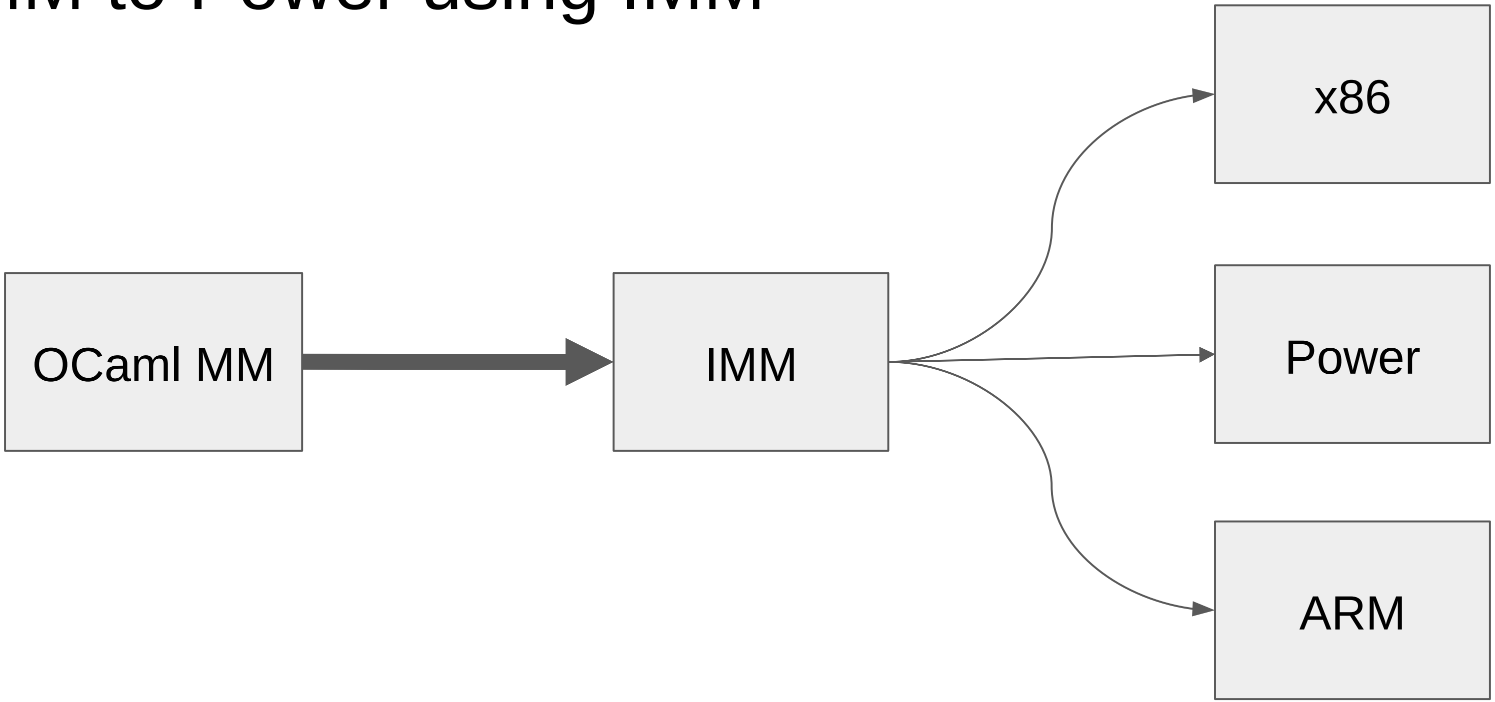


We've proved compilation correctness from OCaml MM to Power using IMM



Another execution representation is needed

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Consider the execution as a graph

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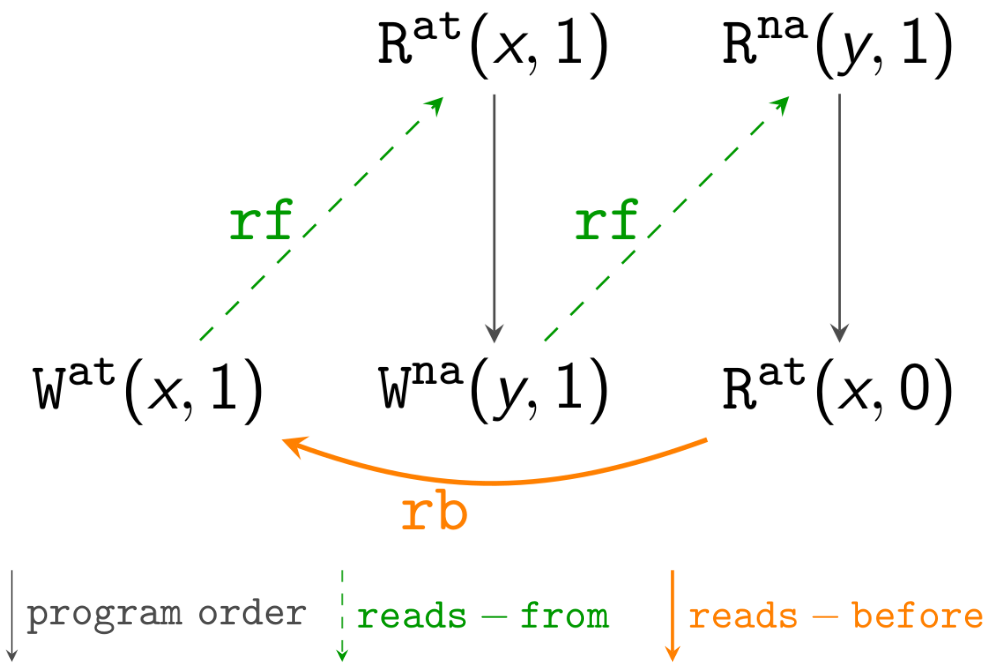

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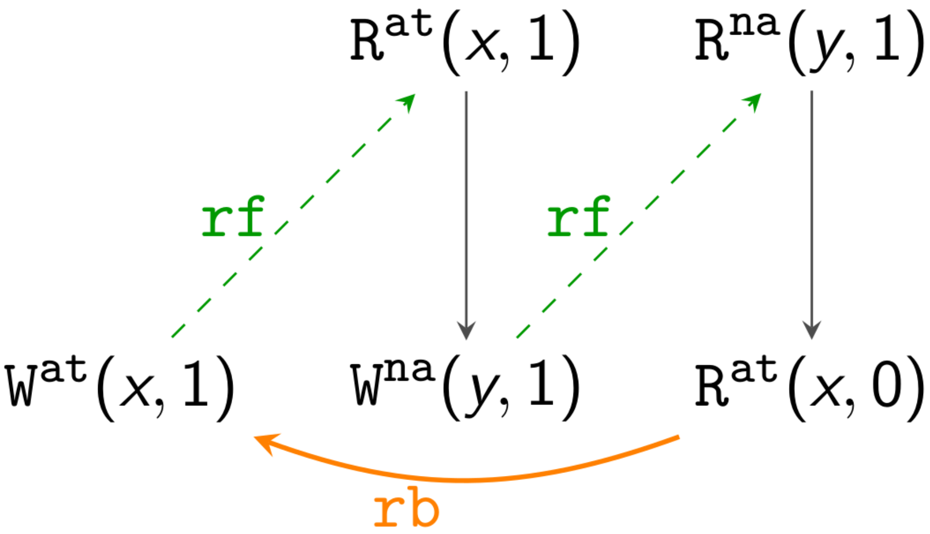

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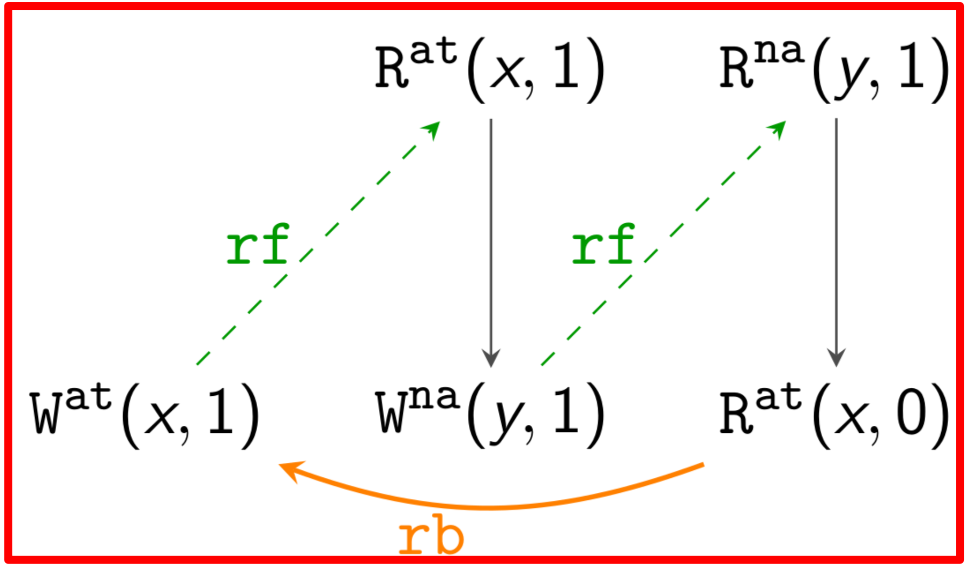
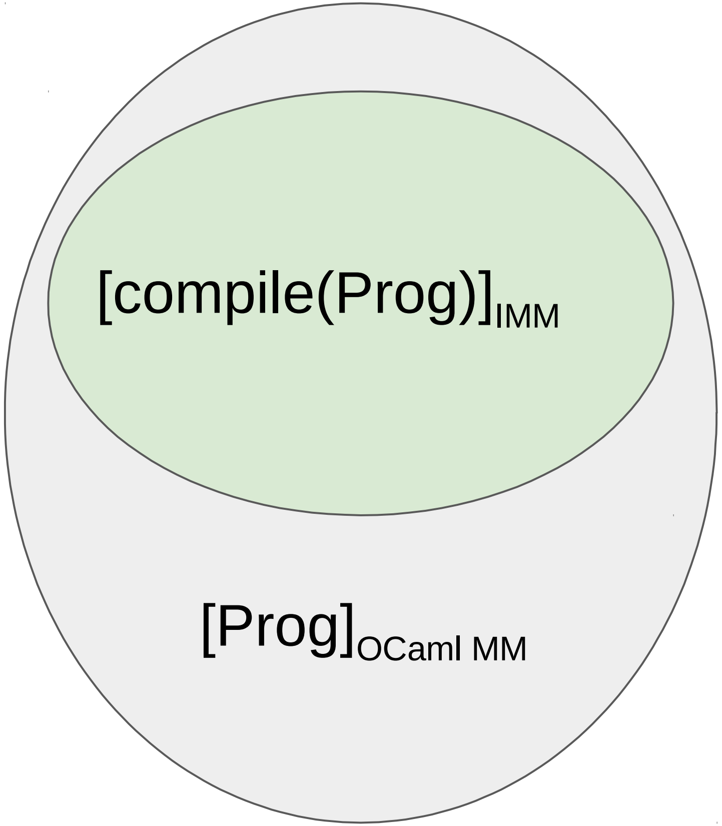


OMM: no cycles made of **po**, **rf** and **rb**

Compilation correctness in terms of graphs



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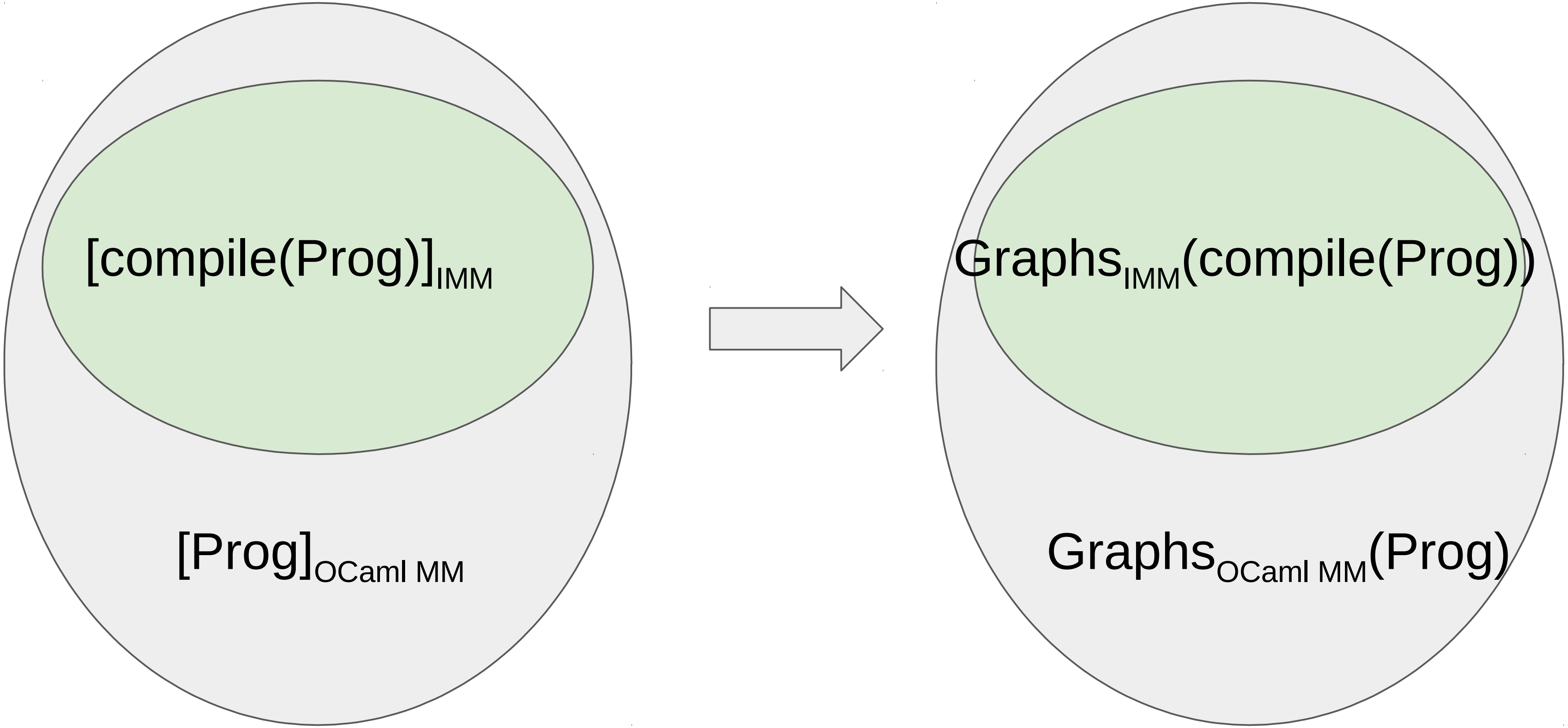

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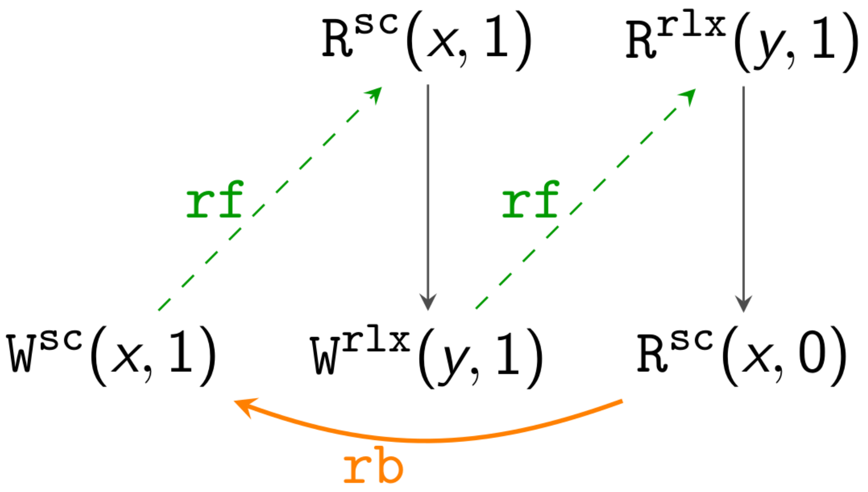

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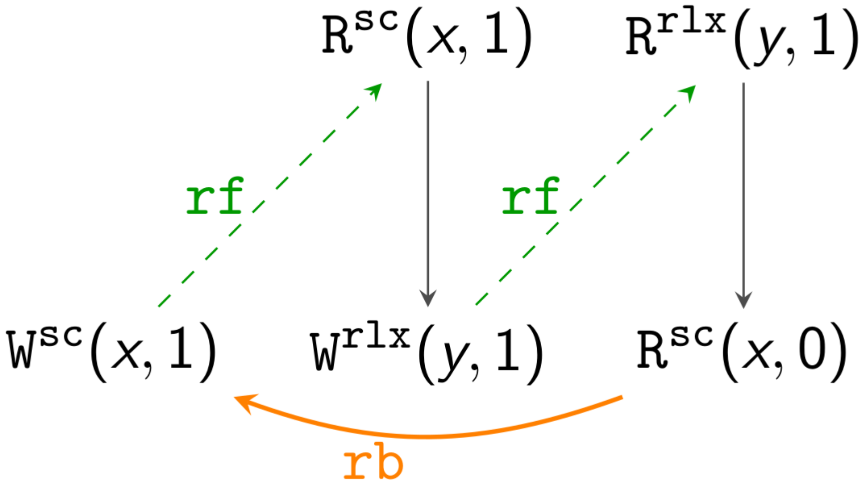

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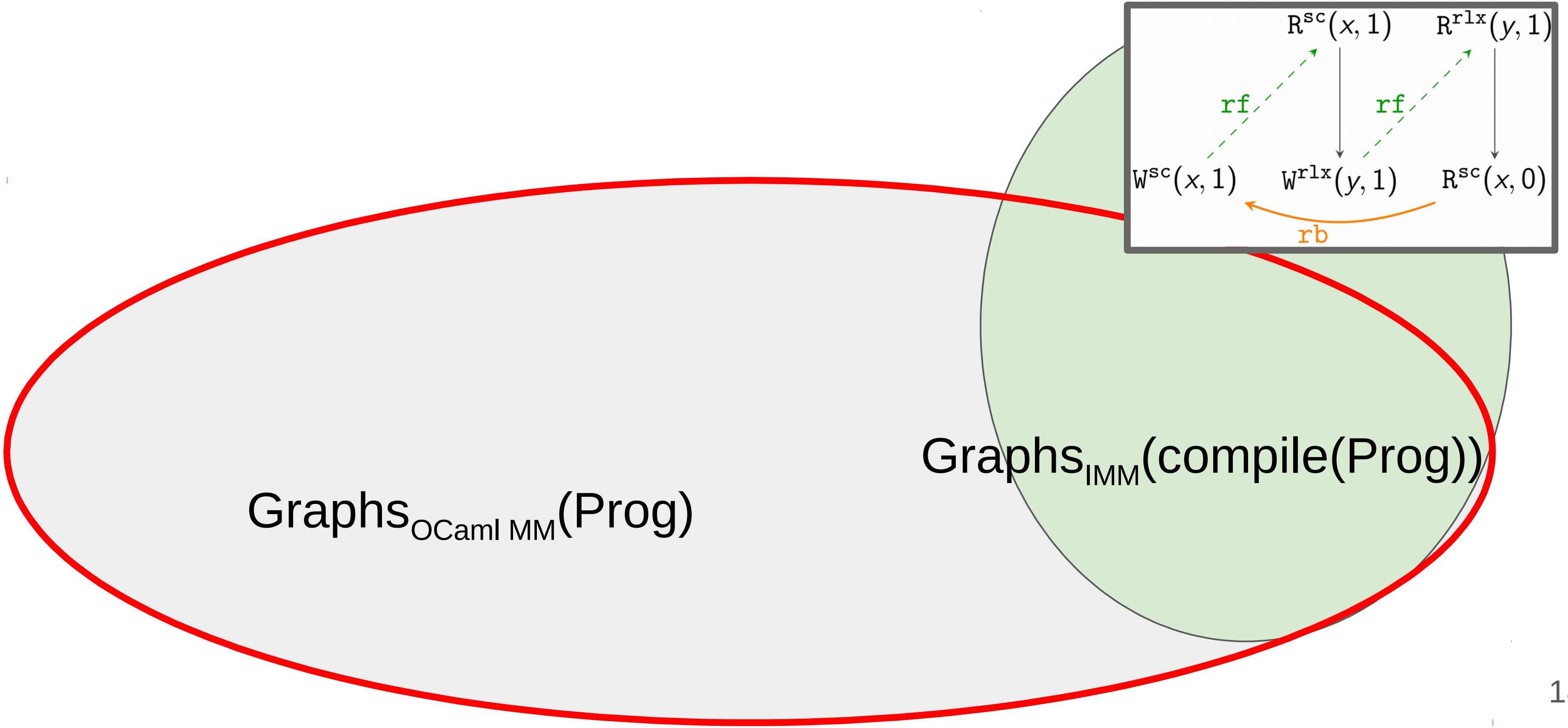

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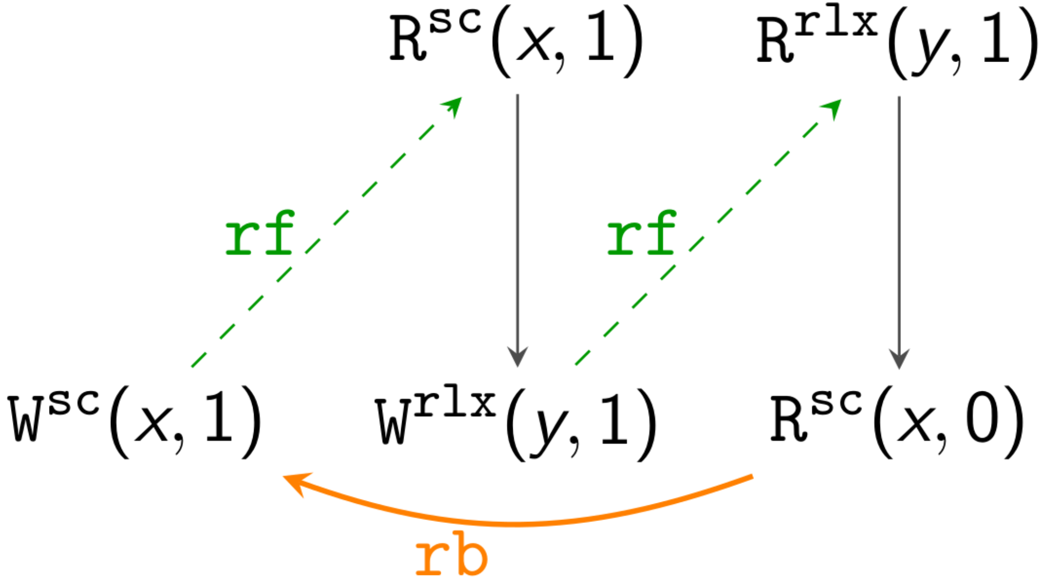

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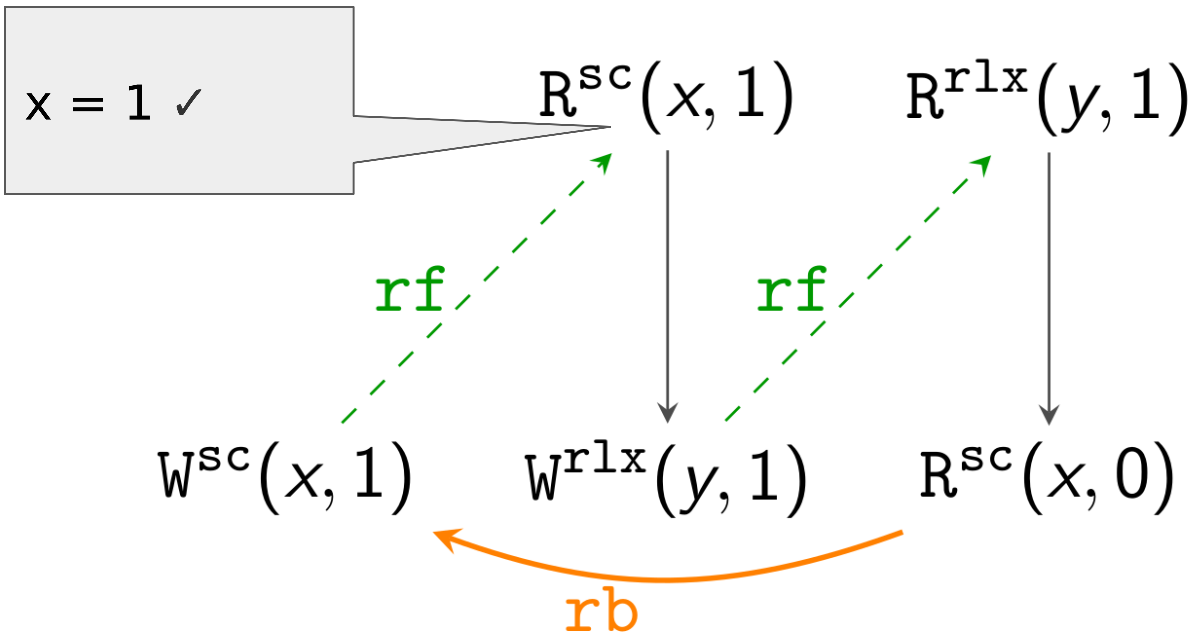

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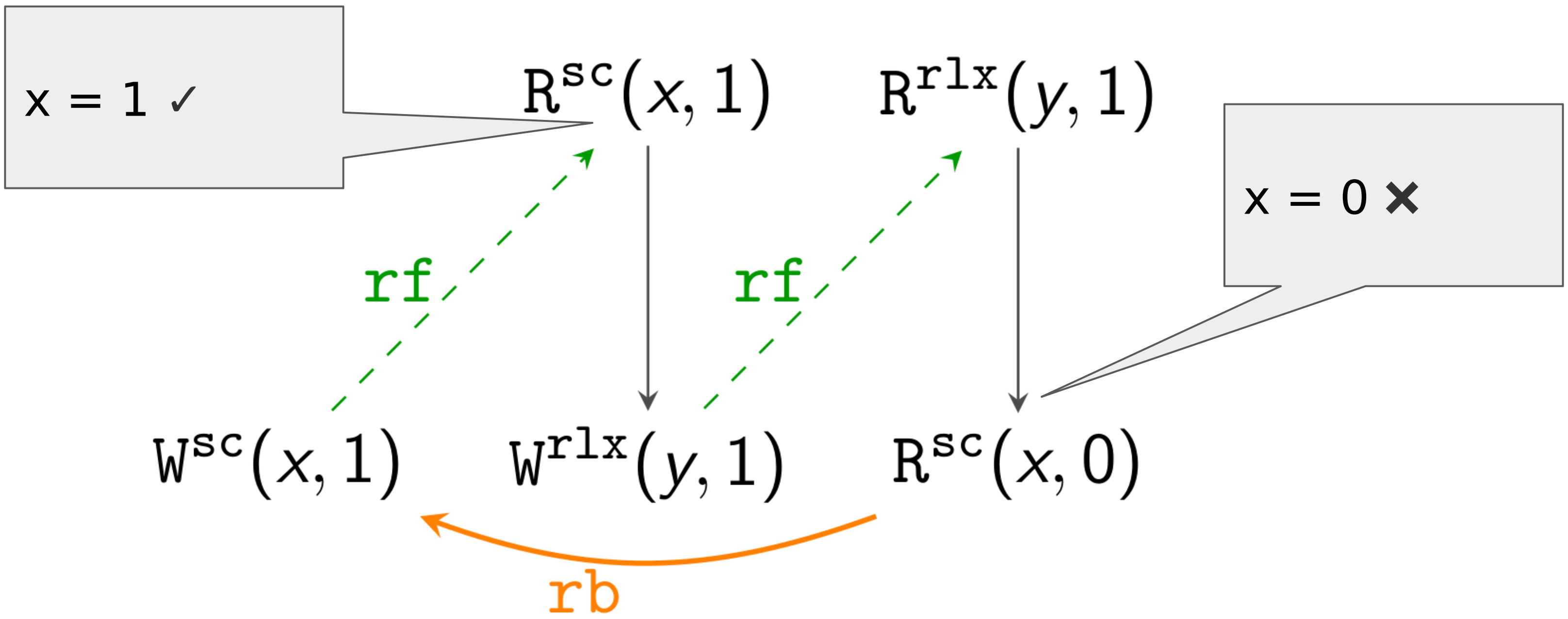
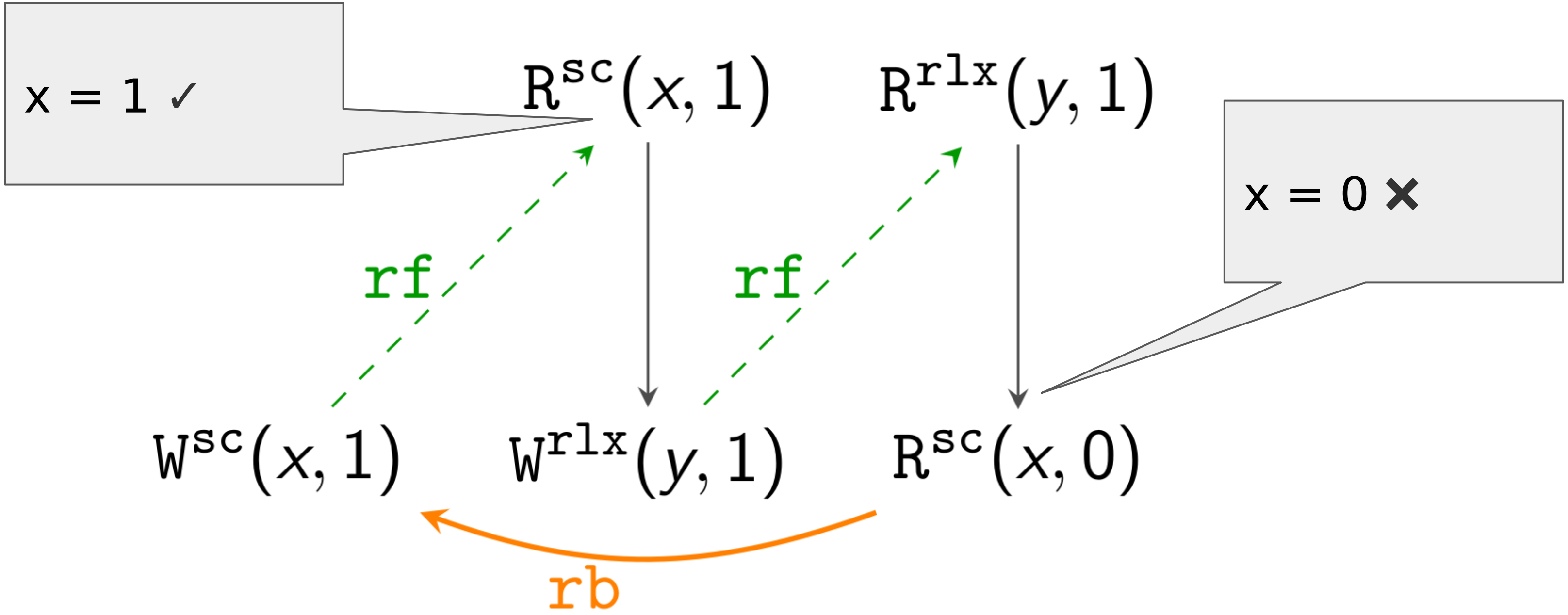


Observed writes should remain so
= graph should have no cycles with rb



“Release” known writes and “acquire” them next

$$
\begin{tikzcd}
& \mathtt{R}^{\mathtt{sc}}(x, 1) \arrow[d] & \mathtt{R}^{\mathtt{rlx}}(y, 1) \arrow[d] \\
\mathtt{W}^{\mathtt{sc}}(x, 1) \arrow[ur, dashed, "\mathtt{rf}"] \arrow[rr, bend right, dashed, "\mathtt{rf}"'] & \mathtt{W}^{\mathtt{rlx}}(y, 1) \arrow[ur, dashed, "\mathtt{rf}"] & \mathtt{R}^{\mathtt{sc}}(x, 1)
\end{tikzcd}
$$

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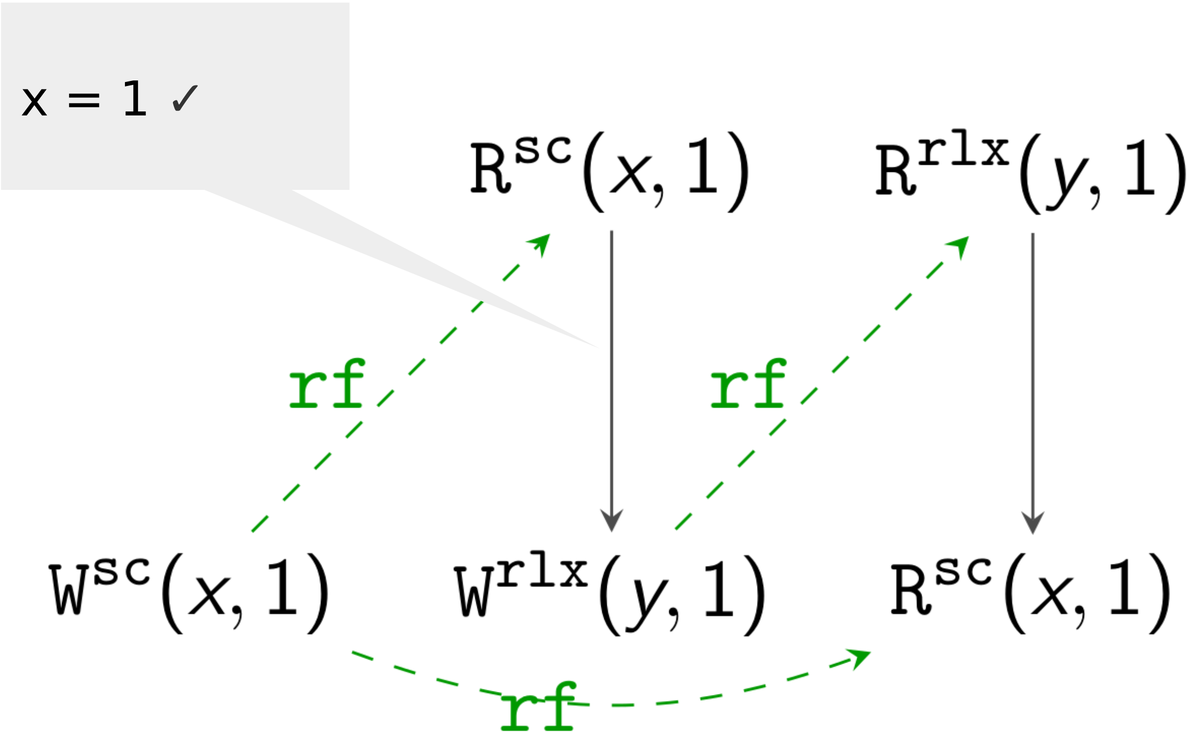

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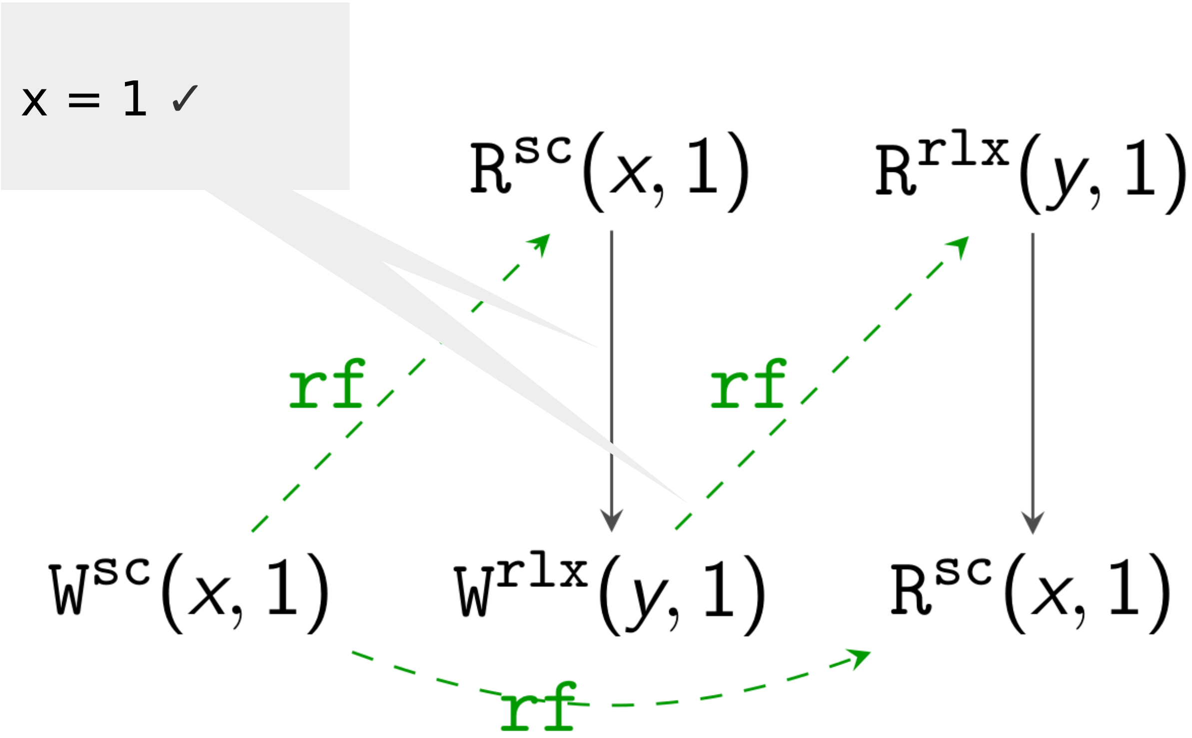

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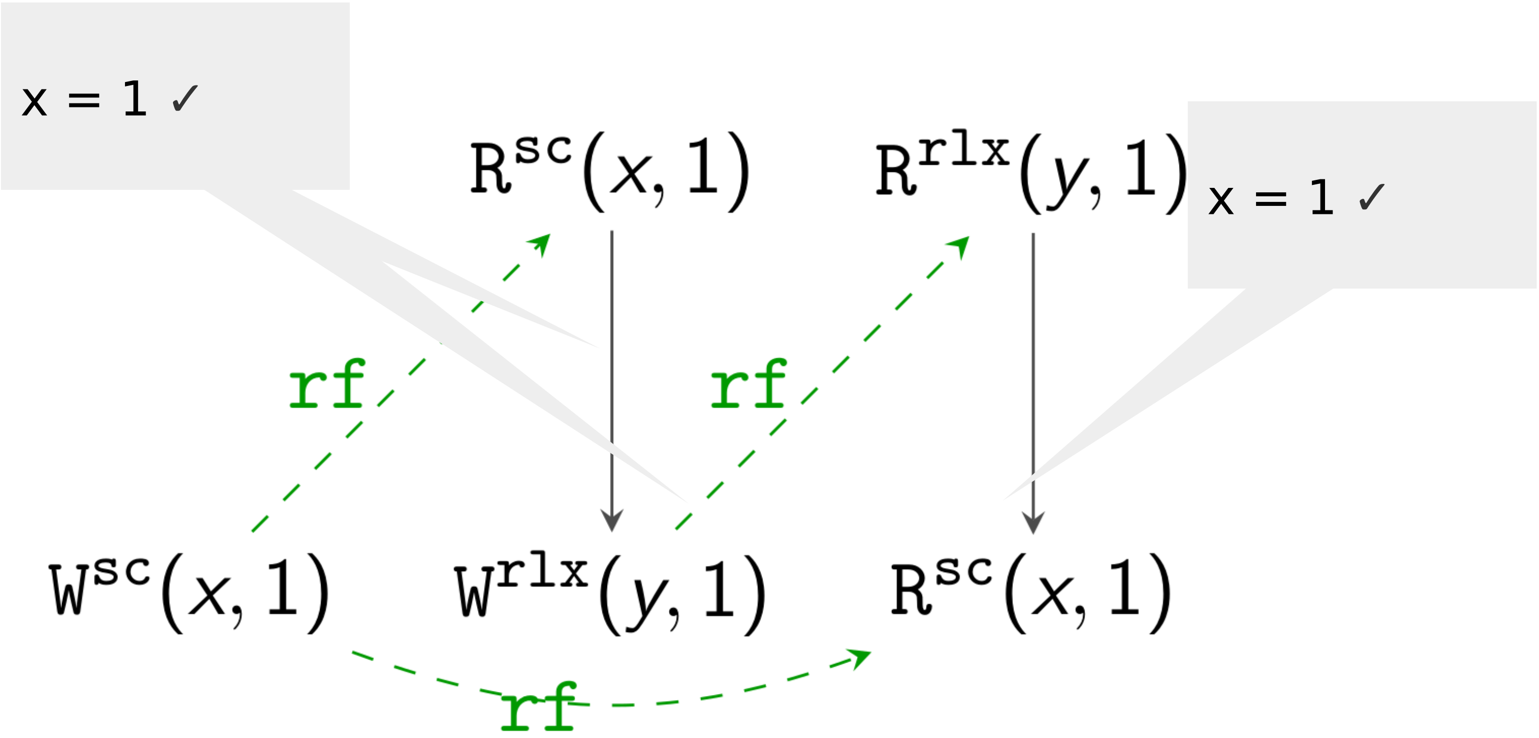

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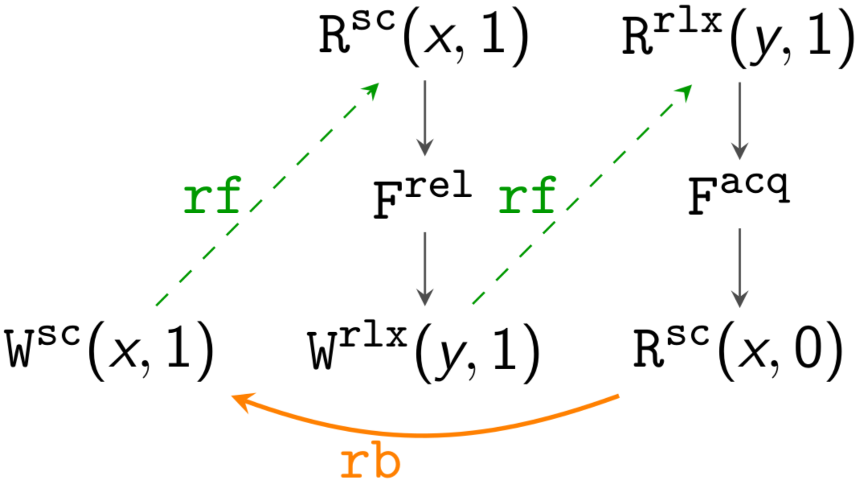

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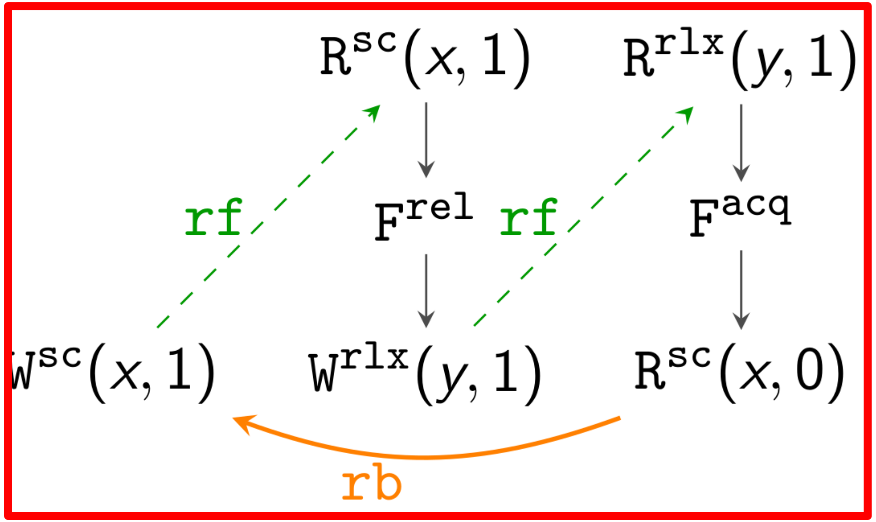
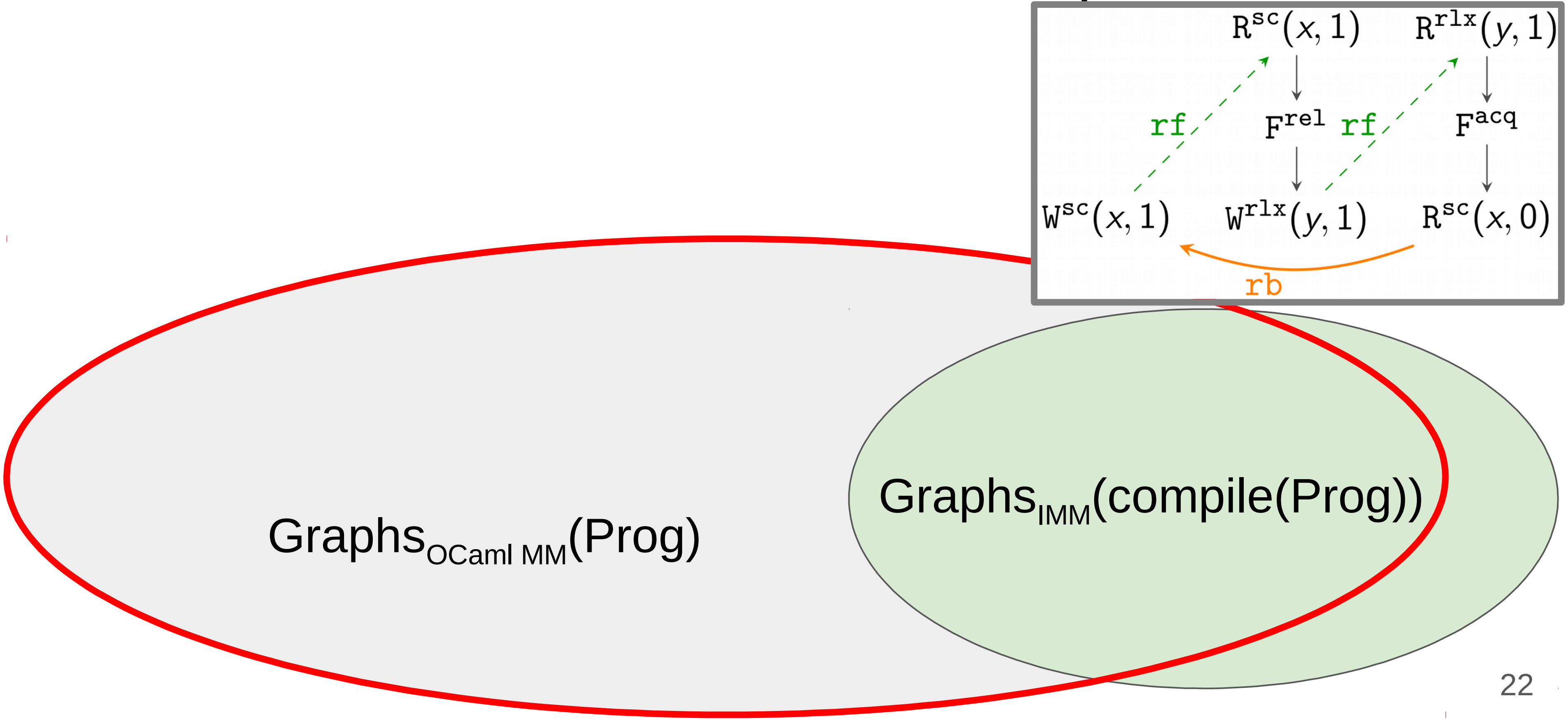


IMM: can have a cycle made of **po**, **rf** and **rb**
if there is **rf** without sc and fences

An IMM-inconsistent behavior is now prohibited



The resulting scheme prohibits unwanted behaviors

OCaml MM	IMM
$\mathtt{r} := [\mathtt{x}]^{\mathtt{na}}$	$\mathtt{r} := [\mathtt{x}]^{\mathtt{rlx}}$
$[\mathtt{x}]^{\mathtt{na}} := \mathtt{v}$	$\mathtt{fence}^{\mathtt{acqrel}}; [\mathtt{x}]^{\mathtt{rlx}} := \mathtt{v}$
$\mathtt{r} := [\mathtt{x}]^{\mathtt{at}}$	$\mathtt{fence}^{\mathtt{acq}}; \mathtt{r} := [\mathtt{x}]^{\mathtt{sc}}$
$[\mathtt{x}]^{\mathtt{at}} := \mathtt{v}$	$\mathtt{fence}^{\mathtt{acq}}; \mathtt{exchange}^{\mathtt{sc}}(\mathtt{x}, \mathtt{v})$

Takeaway

- Compilation scheme from OCaml MM to IMM
- Proved to be correct
- Formalized in Coq

Machine-verified compilation scheme from OCaml MM to Power

https://github.com/weakmemory/imm