[Wil92] Paul R. Wilson. Uniprocessor garbage collection techniques. In International Workshop on Memory Management, volume 637 of Lecture Notes in Computer Science, St. Malo, France, September 1992.
[Win93] Glynn Winskel. The Formal Semantics of Programming Languages: An Introduction. MIT Press, 1993.
[WS97] Mitchell Wand and Gregory T. Sullivan. Denotational semantics using an operationally-based term model. In 24th Symposium on the Principles of Programming Languages (POPL), pages 386-399, 1997.
[You81] Richard M. Young. The machine inside the machine: Users' models of pocket calculators. International Journal of Man-Machine Studies, 15:51-85, 1981.

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