Name:_____

CSE P505, Winter 2009, Final Examination
19 March 2008

Rules:

- The exam is closed-book, closed-note, except for one two-sided 8.5x11in piece of paper.
- **Please stop promptly at 8:20.**
- You can rip apart the pages.
- There are **100 points** total, distributed **unevenly** among **7** questions.
- The questions have multiple parts.

Advice:

- Read questions carefully. Understand a question before you start writing.
- Write down thoughts and intermediate steps so you can get partial credit.
- The questions are not necessarily in order of difficulty. **Skip around.** In particular, make sure you get to all the problems.
- If you have questions, ask.
- Relax. You are here to learn.

Name:_____

For your reference (page 1 of 2):

$$\begin{array}{rcl} s & ::= & \mathsf{skip} \mid x := e \mid s; s \mid \mathsf{if}\ e\ s\ s \mid \mathsf{while}\ e\ s \\ e & ::= & i \mid x \mid e + e \mid e * e \\ (i & \in & \{\ldots, -2, -1, 0, 1, 2, \ldots\}) \\ (x & \in & \{\mathtt{x}_1, \mathtt{x}_2, \ldots, \mathtt{y}_1, \mathtt{y}_2, \ldots, \mathtt{z}_1, \mathtt{z}_2, \ldots, \ldots\}) \end{array}$$

$\boxed{H\ ;\ e\ \Downarrow\ i}$

$$\text{CONST}\ \frac{}{H\ ;\ c\ \Downarrow\ c} \qquad \text{VAR}\ \frac{}{H\ ;\ x\ \Downarrow\ H(x)} \qquad \text{ADD}\ \frac{H\ ;\ e_1\ \Downarrow\ c_1 \qquad H\ ;\ e_2\ \Downarrow\ c_2}{H\ ;\ e_1 + e_2\ \Downarrow\ c_1 + c_2} \qquad \text{MULT}\ \frac{H\ ;\ e_1\ \Downarrow\ c_1 \qquad H\ ;\ e_2\ \Downarrow\ c_2}{H\ ;\ e_1 * e_2\ \Downarrow\ c_1 * c_2}$$

$\boxed{H_1\ ;\ s\ \Downarrow\ H_2}$

$$\text{SKIP}\ \frac{}{H\ ;\ \mathsf{skip}\ \Downarrow\ H} \qquad \text{ASSIGN}\ \frac{H\ ;\ e\ \Downarrow\ i}{H\ ;\ x := e\ \Downarrow\ H, x \mapsto i} \qquad \text{SEQ}\ \frac{H_1\ ;\ s_1\ \Downarrow\ H_3 \qquad H_3\ ;\ s_2\ \Downarrow\ H_2}{H_1\ ;\ s_1; s_2\ \Downarrow\ H_2}$$

$$\text{IF1}\ \frac{H_1\ ;\ e\ \Downarrow\ i \quad i \neq 0 \quad H_1\ ;\ s_1\ \Downarrow\ H_2}{H_1\ ;\ \mathsf{if}\ e\ s_1\ s_2\ \Downarrow\ H_2} \qquad \text{IF2}\ \frac{H_1\ ;\ e\ \Downarrow\ 0 \quad H_1\ ;\ s_2\ \Downarrow\ H_2}{H_1\ ;\ \mathsf{if}\ e\ s_1\ s_2\ \Downarrow\ H_2} \qquad \text{WHILE}\ \frac{H_1\ ;\ \mathsf{if}\ e\ (s; \mathsf{while}\ e\ s)\ \mathsf{skip}\ \Downarrow\ H_2}{H_1\ ;\ \mathsf{while}\ e\ s\ \Downarrow\ H_2}$$

$$\begin{array}{rcl} e & ::= & \lambda x.\ e \mid x \mid e\ e \mid c \mid (e, e) \mid e.1 \mid e.2 \mid \{l_1 = e_1, \ldots, l_n = e_n\} \mid e.l_i \\ & \mid & \mathsf{letrec}\ f\ x.\ e \mid \mathsf{A}(e) \mid \mathsf{B}(e) \mid (\mathsf{match}\ e\ \mathsf{with}\ \mathsf{A}x.\ e \mid \mathsf{B}x.\ e) \\ v & ::= & \lambda x.\ e \mid c \mid \mathsf{letrec}\ f\ x.\ e \mid (v, v) \mid \{l_1 = v_1, \ldots, l_n = v_n\} \mid \mathsf{A}(v) \mid \mathsf{B}(v) \\ \tau & ::= & \mathsf{int} \mid \tau \to \tau \mid \tau * \tau \mid \{l_1 : \tau_1, \ldots, l_n : \tau_n\} \mid \tau + \tau \end{array}$$

$\boxed{e_1 \to e_2}$

$$\frac{}{(\lambda x.\ e)\ v \to e\{v/x\}} \qquad \frac{e_1 \to e_1'}{e_1\ e_2 \to e_1'\ e_2} \qquad \frac{e_2 \to e_2'}{v\ e_2 \to v\ e_2'} \qquad \frac{e_1 \to e_1'}{(e_1, e_2) \to (e_1', e_2)} \qquad \frac{e_2 \to e_2'}{(v, e_2) \to (v, e_2')}$$

$$\frac{e \to e'}{e.1 \to e'.1} \qquad \frac{e \to e'}{e.2 \to e'.2} \qquad \frac{}{(v_1, v_2).1 \to v_1} \qquad \frac{}{(v_1, v_2).2 \to v_2}$$

$$\frac{}{(\mathsf{letrec}\ f\ x.\ e)\ v \to (e\{v/x\})\{\mathsf{letrec}\ f\ x.\ e/f\}} \qquad \frac{}{\{l_1 = v_1, \ldots, l_n = v_n\}.l_i \to v_i}$$

$$\frac{e_i \to e_i'}{\{l_1 = v_1, \ldots, l_{i-1} = v_{i-1}, l_i = e_i, \ldots, l_n = e_n\} \to \{l_1 = v_1, \ldots, l_{i-1} = v_{i-1}, l_i = e_i', \ldots, l_n = e_n\}}$$

$$\frac{}{\mathsf{match}\ \mathsf{A}(v)\ \mathsf{with}\ \mathsf{A}x.\ e_1 \mid \mathsf{B}y.\ e_2 \to e_1\{v/x\}} \qquad \frac{}{\mathsf{match}\ \mathsf{B}(v)\ \mathsf{with}\ \mathsf{A}x.\ e_1 \mid \mathsf{B}y.\ e_2 \to e_2\{v/y\}}$$

$$\frac{e \to e'}{\mathsf{A}(e) \to \mathsf{A}(e')} \qquad \frac{e \to e'}{\mathsf{B}(e) \to \mathsf{B}(e')} \qquad \frac{e \to e'}{\mathsf{match}\ e\ \mathsf{with}\ \mathsf{A}x.\ e_1 \mid \mathsf{B}y.\ e_2 \to \mathsf{match}\ e'\ \mathsf{with}\ \mathsf{A}x.\ e_1 \mid \mathsf{B}y.\ e_2}$$

$\boxed{\Gamma \vdash e : \tau}$

$$\frac{}{\Gamma \vdash c : \mathsf{int}} \qquad \frac{}{\Gamma \vdash x : \Gamma(x)} \qquad \frac{\Gamma, x : \tau_1 \vdash e : \tau_2}{\Gamma \vdash \lambda x.\ e : \tau_1 \to \tau_2} \qquad \frac{\Gamma \vdash e_1 : \tau_2 \to \tau_1 \qquad \Gamma \vdash e_2 : \tau_2}{\Gamma \vdash e_1\ e_2 : \tau_1}$$

$$\frac{\Gamma \vdash e_1 : \tau_1 \qquad \Gamma \vdash e_2 : \tau_2}{\Gamma \vdash (e_1, e_2) : \tau_1 * \tau_2} \qquad \frac{\Gamma \vdash e : \tau_1 * \tau_2}{\Gamma \vdash e.1 : \tau_1} \qquad \frac{\Gamma \vdash e : \tau_1 * \tau_2}{\Gamma \vdash e.2 : \tau_2} \qquad \frac{\Gamma, f : \tau_1 \to \tau_2, x : \tau_1 \vdash e : \tau_2}{\Gamma \vdash \mathsf{letrec}\ f\ x.\ e : \tau_1 \to \tau_2}$$

$$\frac{\Gamma \vdash e_1 : \tau_1 \qquad \ldots \qquad \Gamma \vdash e_n : \tau_n \qquad \text{labels distinct}}{\Gamma \vdash \{l_1 = e_1, \ldots, l_n = e_n\} : \{l_1 : \tau_1, \ldots, l_n : \tau_n\}} \qquad \frac{\Gamma \vdash e : \{l_1 : \tau_1, \ldots, l_n : \tau_n\} \qquad 1 \le i \le n}{\Gamma \vdash e.l_i : \tau_i}$$

$$\frac{\Gamma \vdash e : \tau_1 + \tau_2 \qquad \Gamma, x{:}\tau_1 \vdash e_1 : \tau \qquad \Gamma, y{:}\tau_2 \vdash e_2 : \tau}{\Gamma \vdash \mathsf{match}\ e\ \mathsf{with}\ \mathsf{A}x.\ e_1 \mid \mathsf{B}y.\ e_2 : \tau} \qquad \frac{\Gamma \vdash e : \tau_1}{\Gamma \vdash \mathsf{A}(e) : \tau_1 + \tau_2} \qquad \frac{\Gamma \vdash e : \tau_2}{\Gamma \vdash \mathsf{B}(e) : \tau_1 + \tau_2}$$

$$\frac{\Gamma \vdash e : \tau \qquad \tau \le \tau'}{\Gamma \vdash e : \tau'}$$

$\boxed{\tau_1 \le \tau_2}$

$$\frac{}{\{l_1{:}\tau_1, \ldots, l_n{:}\tau_n, l{:}\tau\} \le \{l_1{:}\tau_1, \ldots, l_n{:}\tau_n\}}$$

$$\frac{}{\{l_1{:}\tau_1, \ldots, l_{i-1}{:}\tau_{i-1}, l_i{:}\tau_i, \ldots, l_n{:}\tau_n\} \le \{l_1{:}\tau_1, \ldots, l_i{:}\tau_i, l_{i-1}{:}\tau_{i-1}, \ldots, l_n{:}\tau_n\}}$$

$$\frac{\tau_i \le \tau_i'}{\{l_1{:}\tau_1, \ldots, l_i{:}\tau_i, \ldots, l_n{:}\tau_n\} \le \{l_1{:}\tau_1, \ldots, l_i{:}\tau_i', \ldots, l_n{:}\tau_n\}}$$

$$\frac{\tau_3 \le \tau_1 \qquad \tau_2 \le \tau_4}{\tau_1 \to \tau_2 \le \tau_3 \to \tau_4} \qquad \frac{}{\tau \le \tau} \qquad \frac{\tau_1 \le \tau_2 \qquad \tau_2 \le \tau_3}{\tau_1 \le \tau_3}$$

Module Thread:

```
type t
val create : ('a -> 'b) -> 'a -> t
val join : t -> unit
```

Module Mutex:

```
type t
val create : unit -> t
val lock : t -> unit
val unlock : t -> unit
```

Module Event:

```
type 'a channel
type 'a event
val new_channel : unit -> 'a channel
val send : 'a channel -> 'a -> unit event
val receive : 'a channel -> 'a event
val choose : 'a event list -> 'a event
val wrap : 'a event -> ('a -> 'b) -> 'b event
val sync : 'a event -> 'a
```