

Name: _____

CSE505, Winter 2012, Final Examination
March 12, 2012

Rules:

- The exam is closed-book, closed-notes, except for one side of one 8.5x11in piece of paper.
- **Please stop promptly at 2:20.**
- You can rip apart the pages.
- There are **100 points** total, distributed **unevenly** among **7** questions, most of which 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.

For your reference (page 1 of 2):

$$\begin{aligned}
e &::= \lambda x. e \mid x \mid e e \mid c \mid \{l_1 = e_1, \dots, l_n = e_n\} \mid e.l_i \mid \text{fix } e \\
v &::= \lambda x. e \mid c \mid \{l_1 = v_1, \dots, l_n = v_n\} \\
\tau &::= \text{int} \mid \tau \rightarrow \tau \mid \{l_1 : \tau_1, \dots, l_n : \tau_n\}
\end{aligned}$$

$e \rightarrow e'$

$$\frac{}{(\lambda x. e) v \rightarrow e[v/x]} \quad \frac{e_1 \rightarrow e'_1}{e_1 e_2 \rightarrow e'_1 e_2} \quad \frac{e_2 \rightarrow e'_2}{v e_2 \rightarrow v e'_2} \quad \frac{e \rightarrow e'}{\text{fix } e \rightarrow \text{fix } e'} \quad \frac{}{\text{fix } \lambda x. e \rightarrow e[(\text{fix } \lambda x. e)/x]}$$

$$\frac{}{\{l_1 = v_1, \dots, l_n = v_n\}.l_i \rightarrow v_i}$$

$$\frac{e_i \rightarrow e'_i}{\{l_1 = v_1, \dots, l_{i-1} = v_{i-1}, l_i = e_i, \dots, l_n = e_n\} \rightarrow \{l_1 = v_1, \dots, l_{i-1} = v_{i-1}, l_i = e'_i, \dots, l_n = e_n\}}$$

$\Gamma \vdash e : \tau$

$$\frac{}{\Gamma \vdash c : \text{int}} \quad \frac{}{\Gamma \vdash x : \Gamma(x)} \quad \frac{\Gamma, x : \tau_1 \vdash e : \tau_2}{\Gamma \vdash \lambda x. e : \tau_1 \rightarrow \tau_2} \quad \frac{\Gamma \vdash e_1 : \tau_2 \rightarrow \tau_1 \quad \Gamma \vdash e_2 : \tau_2}{\Gamma \vdash e_1 e_2 : \tau_1} \quad \frac{\Gamma \vdash e : \tau \rightarrow \tau}{\Gamma \vdash \text{fix } e : \tau}$$

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

$$\frac{\Gamma \vdash e : \tau \quad \tau \leq \tau'}{\Gamma \vdash e : \tau'}$$

$\tau_1 \leq \tau_2$

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

$$\frac{}{\{l_1 : \tau_1, \dots, l_n : \tau_n, l : \tau\} \leq \{l_1 : \tau_1, \dots, l_n : \tau_n\}} \quad \frac{\tau_i \leq \tau'_i}{\{l_1 : \tau_1, \dots, l_i : \tau_i, \dots, l_n : \tau_n\} \leq \{l_1 : \tau_1, \dots, l_i : \tau'_i, \dots, l_n : \tau_n\}}$$

$$\frac{\tau_3 \leq \tau_1 \quad \tau_2 \leq \tau_4}{\tau_1 \rightarrow \tau_2 \leq \tau_3 \rightarrow \tau_4}$$

$$\frac{}{\tau \leq \tau}$$

$$\frac{\tau_1 \leq \tau_2 \quad \tau_2 \leq \tau_3}{\tau_1 \leq \tau_3}$$

$$\begin{aligned}
e &::= c \mid x \mid \lambda x : \tau. e \mid e e \mid \Lambda \alpha. e \mid e[\tau] \\
\tau &::= \text{int} \mid \tau \rightarrow \tau \mid \alpha \mid \forall \alpha. \tau \\
v &::= c \mid \lambda x : \tau. e \mid \Lambda \alpha. e
\end{aligned}$$

$$\begin{aligned}
\Gamma &::= \cdot \mid \Gamma, x : \tau \\
\Delta &::= \cdot \mid \Delta, \alpha
\end{aligned}$$

$e \rightarrow e'$

$$\frac{e_1 \rightarrow e'_1}{e_1 e_2 \rightarrow e'_1 e_2} \quad \frac{e_2 \rightarrow e'_2}{v e_2 \rightarrow v e'_2} \quad \frac{e \rightarrow e'}{e[\tau] \rightarrow e'[\tau]} \quad \frac{}{(\lambda x : \tau. e) v \rightarrow e[v/x]} \quad \frac{}{(\Lambda \alpha. e)[\tau] \rightarrow e[\tau/\alpha]}$$

$\Delta; \Gamma \vdash e : \tau$

$$\frac{}{\Delta; \Gamma \vdash x : \Gamma(x)} \quad \frac{}{\Delta; \Gamma \vdash c : \text{int}} \quad \frac{\Delta; \Gamma, x : \tau_1 \vdash e : \tau_2 \quad \Delta \vdash \tau_1}{\Delta; \Gamma \vdash \lambda x : \tau_1. e : \tau_1 \rightarrow \tau_2} \quad \frac{\Delta, \alpha; \Gamma \vdash e : \tau_1}{\Delta; \Gamma \vdash \Lambda \alpha. e : \forall \alpha. \tau_1}$$

$$\frac{\Delta; \Gamma \vdash e_1 : \tau_2 \rightarrow \tau_1 \quad \Delta; \Gamma \vdash e_2 : \tau_2}{\Delta; \Gamma \vdash e_1 e_2 : \tau_1}$$

$$\frac{\Delta; \Gamma \vdash e : \forall \alpha. \tau_1 \quad \Delta \vdash \tau_2}{\Delta; \Gamma \vdash e[\tau_2] : \tau_1[\tau_2/\alpha]}$$

For your reference (page 2 of 2):

$$\begin{aligned}
e &::= \dots \mid A(e) \mid B(e) \mid (\text{match } e \text{ with } Ax. e \mid Bx. e) \mid (e, e) \mid e.1 \mid e.2 \\
\tau &::= \dots \mid \tau_1 + \tau_2 \mid \tau_1 * \tau_2 \\
v &::= \dots \mid A(v) \mid B(v) \mid (v, v)
\end{aligned}$$

$e \rightarrow e'$

$$\begin{array}{c}
\frac{e \rightarrow e'}{A(e) \rightarrow A(e')} \quad \frac{e \rightarrow e'}{B(e) \rightarrow B(e')} \quad \frac{e \rightarrow e'}{\text{match } e \text{ with } Ax. e_1 \mid Bx. e_2 \rightarrow \text{match } e' \text{ with } Ax. e_1 \mid Bx. e_2} \\
\frac{}{\text{match } A(v) \text{ with } Ax. e_1 \mid Bx. e_2 \rightarrow e_1[v/x]} \quad \frac{}{\text{match } B(v) \text{ with } Ax. e_1 \mid Bx. e_2 \rightarrow e_2[v/y]} \\
\frac{e_1 \rightarrow e'_1}{(e_1, e_2) \rightarrow (e'_1, e_2)} \quad \frac{e_2 \rightarrow e'_2}{(v, e_2) \rightarrow (v, e'_2)} \quad \frac{e \rightarrow e'}{e.1 \rightarrow e'.1} \quad \frac{e \rightarrow e'}{e.2 \rightarrow e'.2} \quad \frac{}{(v_1, v_2).1 \rightarrow v_1} \quad \frac{}{(v_1, v_2).2 \rightarrow v_2}
\end{array}$$

$\Gamma \vdash e : \tau$

$$\begin{array}{c}
\frac{\Gamma \vdash e : \tau_1 + \tau_2 \quad \Gamma, x:\tau_1 \vdash e_1 : \tau \quad \Gamma, y:\tau_2 \vdash e_2 : \tau}{\Gamma \vdash \text{match } e \text{ with } Ax. e_1 \mid Bx. e_2 : \tau} \quad \frac{\Gamma \vdash e : \tau_1}{\Gamma \vdash A(e) : \tau_1 + \tau_2} \quad \frac{\Gamma \vdash e : \tau_2}{\Gamma \vdash B(e) : \tau_1 + \tau_2} \\
\frac{\Gamma \vdash e_1 : \tau_1 \quad \Gamma \vdash e_2 : \tau_2}{\Gamma \vdash (e_1, e_2) : \tau_1 * \tau_2} \quad \frac{\Gamma \vdash e : \tau_1 * \tau_2}{\Gamma \vdash e.1 : \tau_1} \quad \frac{\Gamma \vdash e : \tau_1 * \tau_2}{\Gamma \vdash e.2 : \tau_2}
\end{array}$$

$$\begin{aligned}
e &::= x \mid \lambda x. e \mid e e \mid (e, e) \mid e.1 \mid e.2 \mid \text{letcc } x. e \mid \text{throw } e e \mid \text{cont } E \\
v &::= \lambda x. e \mid (v, v) \mid \text{cont } E \\
E &::= [\cdot] \mid E e \mid v E \mid (E, e) \mid (v, E) \mid E.1 \mid E.2 \mid \text{throw } E e \mid \text{throw } v E
\end{aligned}$$

$$\begin{array}{c}
\frac{e \xrightarrow{P} e'}{E[e] \rightarrow E[e']} \quad \frac{}{E[\text{letcc } x. e] \rightarrow E[(\lambda x. e)(\text{cont } E)]} \quad \frac{}{E[\text{throw } (\text{cont } E') v] \rightarrow E'[v]} \\
\frac{}{(\lambda x. e) v \xrightarrow{P} e[v/x]} \quad \frac{}{(v_1, v_2).1 \xrightarrow{P} v_1} \quad \frac{}{(v_1, v_2).2 \xrightarrow{P} v_2}
\end{array}$$

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

```

Futures:

```

type 'a promise
val future : (unit -> 'a) -> 'a promise
val force : 'a promise -> 'a

```

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

```