# Ocaml

KOSMOS

# 새로운 언어

여기까지는 우리가 앞서 공부한 내용이에요

$$
\begin{aligned}
F &\rightarrow E \\
E &\rightarrow n \\
&\mid x \\
&\mid E + E \\
&\mid E - E \\
&\mid E * E \\
&\mid E / E \\
&\mid \text{let } x = E \text{ in } E \\
&\mid \text{let } f(x) = E \text{ in } E \\
&\mid E(E)
\end{aligned}
$$

# 새로운 언어

여기까지는 우리가 앞서 공부한 내용이에요

$$Val = N + Procedure$$
$$Procedure = Var \times E \times Env$$
$$Env = Var \to Val$$

# 새로운 언어

여기까지는 우리가 앞서 공부한 내용이에요

$$\frac{}{\rho \vdash n \Rightarrow n} \qquad \frac{}{\rho \vdash x \Rightarrow \rho(x)}$$

$$\frac{\rho \vdash E_1 \Rightarrow n_1 \quad \rho \vdash E_2 \Rightarrow n_2}{\rho \vdash E_1 + E_2 \Rightarrow n_1 + n_2} \qquad \frac{\rho \vdash E_1 \Rightarrow n_1 \quad \rho \vdash E_2 \Rightarrow n_2}{\rho \vdash E_1 - E_2 \Rightarrow n_1 - n_2}$$

$$\frac{\rho \vdash E_1 \Rightarrow n_1 \quad \rho \vdash E_2 \Rightarrow n_2}{\rho \vdash E_1 * E_2 \Rightarrow n_1 * n_2} \qquad \frac{\rho \vdash E_1 \Rightarrow n_1 \quad \rho \vdash E_2 \Rightarrow n_2}{\rho \vdash E_1 / E_2 \Rightarrow n_1 / n_2} \; n_2 \neq 0$$

$$\frac{\rho \vdash E_1 \Rightarrow n \quad [x \longmapsto n]\rho \vdash E_2 \Rightarrow v}{\rho \vdash \text{let } x = E_1 \text{ in } E_2 \Rightarrow v}$$

$$\frac{[f \longmapsto (x, E_1, \rho)]\rho \vdash E_2 \Rightarrow v}{\rho \vdash \text{let } f(x) = E_1 \text{ in } E_2 \Rightarrow v} \qquad \frac{\rho \vdash E_1 \Rightarrow (x, E, \rho') \quad \rho \vdash E_2 \Rightarrow v' \quad [x \longmapsto v']\rho' \vdash E \Rightarrow v}{\rho \vdash E_1(E_2) \Rightarrow v}$$

# Recursive Procedure

$$Procedure = Var \times Var \times E \times Env$$

$$\frac{[f \longmapsto (f, x, E_1, \rho)]\rho \vdash E_2 \Rightarrow v}{\rho \vdash \text{let } f(x) = E_1 \text{ in } E_2 \Rightarrow v}$$

$$\frac{\rho \vdash E_1 \Rightarrow (f, x, E, \rho') \quad \rho \vdash E_2 \Rightarrow v' \quad [x \longmapsto v', f \longmapsto (f, x, E, \rho')]\rho' \vdash E \Rightarrow v}{\rho \vdash E_1(E_2) \Rightarrow v}$$

# if … then … else …

간단한 조건문을 추가 할 거에요

$$
\begin{aligned}
E \rightarrow\ & \cdots \\
\mid\ & E == E \\
\mid\ & E < E \\
\mid\ & \text{not } E \\
\mid\ & \text{if } E \text{ then } E \text{ else } E
\end{aligned}
$$

# if … then … else

$$Val = N + Bool + Procedure$$
$$Procedure = Var \times Var \times E \times Env$$
$$Env = Var \to Val$$

$$\frac{\rho \vdash E_1 \Rightarrow n_1 \quad \rho \vdash E_2 \Rightarrow n_2}{\rho \vdash E_1 == E_2 \Rightarrow true} \; n_1 = n_1$$

$$\frac{\rho \vdash E_1 \Rightarrow b_1 \quad \rho \vdash E_2 \Rightarrow b_2}{\rho \vdash E_1 == E_2 \Rightarrow true} \; b_1 = b_1$$

$$\frac{\rho \vdash E_1 \Rightarrow n_1 \quad \rho \vdash E_2 \Rightarrow n_2}{\rho \vdash E_1 < E_2 \Rightarrow true} \; n_1 < n_1$$

$$\frac{\rho \vdash E \Rightarrow true}{\rho \vdash \text{not } E \Rightarrow false}$$

$$\frac{\rho \vdash E_1 \Rightarrow true \quad \rho \vdash E_2 \Rightarrow v}{\rho \vdash \text{if } E_1 \text{ then } E_2 \text{ else } E_3 \Rightarrow v}$$

$$\frac{\rho \vdash E_1 \Rightarrow n_1 \quad \rho \vdash E_2 \Rightarrow n_2}{\rho \vdash E_1 == E_2 \Rightarrow false} \; n_1 \neq n_2$$

$$\frac{\rho \vdash E_1 \Rightarrow b_1 \quad \rho \vdash E_2 \Rightarrow b}{\rho \vdash E_1 == E_2 \Rightarrow false} \; b_1 \neq b_2$$

$$\frac{\rho \vdash E_1 \Rightarrow n_1 \quad \rho \vdash E_2 \Rightarrow n_2}{\rho \vdash E_1 == E_2 \Rightarrow false} \; n_1 \geq n_2$$

$$\frac{\rho \vdash E \Rightarrow false}{\rho \vdash \text{not } E \Rightarrow true}$$

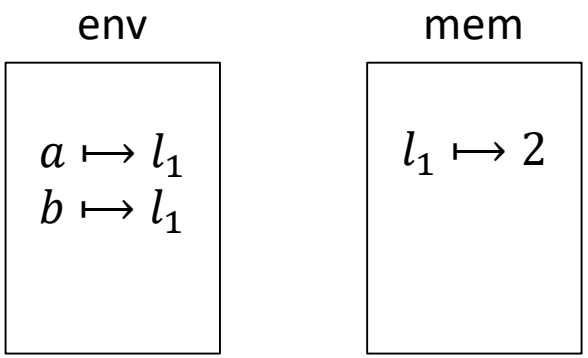
$$\frac{\rho \vdash E_1 \Rightarrow false \quad \rho \vdash E_3 \Rightarrow v}{\rho \vdash \text{if } E_1 \text{ then } E_2 \text{ else } E_3 \Rightarrow v}$$

# State & Memory

프로그램 전체 실행 중에서 변수의 스코프와 관계없이 항상 유지되는 공간

```
let a = ref 1 in
let b = a in
b := 2 in
!a
```

위 식의 계산 결과는 2에요



# State & Memory

$$
\begin{aligned}
E \rightarrow\ & \cdots \\
\mid\ & () \\
\mid\ & \text{ref}\, E \\
\mid\ & !\, E \\
\mid\ & x := E \text{ in } E \\
\mid\ & E; E
\end{aligned}
$$

# State & Memory

$$Val = Unit + N + B + Procedure + Loc$$
$$Procedure = Var \times Var \times E \times Env$$
$$Env = Var \to Val$$
$$Mem = Loc \to Val$$

$$\frac{}{\rho,s \vdash n \Rightarrow n,s} \qquad \frac{}{\rho,s \vdash x \Rightarrow \rho(x),s}$$

$$\frac{\rho,s \vdash E_1 \Rightarrow n_1,s' \quad \rho,s' \vdash E_2 \Rightarrow n_2,s''}{\rho,s \vdash E_1 + E_2 \Rightarrow n_1 + n_2,s''} \qquad \frac{\rho,s \vdash E_1 \Rightarrow n_1,s' \quad \rho,s' \vdash E_2 \Rightarrow n_2,s''}{\rho,s \vdash E_1 - E_2 \Rightarrow n_1 - n_2,s''}$$

$$\frac{\rho,s \vdash E_1 \Rightarrow n_1,s' \quad \rho,s' \vdash E_2 \Rightarrow n_2,s''}{\rho,s \vdash E_1 * E_2 \Rightarrow n_1 * n_2,s''} \qquad \frac{\rho,s \vdash E_1 \Rightarrow n_1,s' \quad \rho,s' \vdash E_2 \Rightarrow n_2,s''}{\rho,s \vdash E_1 / E_2 \Rightarrow n_1 / n_2,s''} \; n_2 \neq 0$$

$$\frac{\rho,s \vdash E_1 \Rightarrow n,s' \quad [x \mapsto n]\rho,s' \vdash E_2 \Rightarrow v,s''}{\rho,s \vdash \text{let } x = E_1 \text{ in } E_2 \Rightarrow v,s''}$$

$$\frac{[f \mapsto (f,x,E_1,\rho)]\rho,s \vdash E_2 \Rightarrow v,s'}{\rho,s \vdash \text{let } f(x) = E_1 \text{ in } E_2 \Rightarrow v,s'}$$

$$\frac{\rho,s \vdash E_1 \Rightarrow (f,x,E,\rho'),s' \quad \rho,s' \vdash E_2 \Rightarrow v',s'' \quad [x \mapsto v', f \mapsto (f,x,E,\rho')]\rho',s'' \vdash E \Rightarrow v,s'''}{\rho,s \vdash E_1(E_2) \Rightarrow v,s'''}$$

# State & Memory

$$\frac{\rho,s\vdash E_1\Rightarrow n_1,s' \quad \rho,s'\vdash E_2\Rightarrow n_2,s''}{\rho,s\vdash E_1==E_2\Rightarrow true,s''}\ n_1 = n_1$$

$$\frac{\rho,s\vdash E_1\Rightarrow n_1,s' \quad \rho,s'\vdash E_2\Rightarrow n_2,s''}{\rho,s\vdash E_1==E_2\Rightarrow false,s''}\ n_1 \neq n_2$$

$$\frac{\rho,s\vdash E_1\Rightarrow b_1,s' \quad \rho,s'\vdash E_2\Rightarrow b_2,s''}{\rho,s\vdash E_1==E_2\Rightarrow true,s''}\ b_1 = b_1$$

$$\frac{\rho,s\vdash E_1\Rightarrow b_1,s' \quad \rho,s'\vdash E_2\Rightarrow b_2,s''}{\rho,s\vdash E_1==E_2\Rightarrow false,s''}\ b_1 \neq b_2$$

$$\frac{\rho,s\vdash E_1\Rightarrow b_1,s' \quad \rho,s'\vdash E_2\Rightarrow b_2,s''}{\rho,s\vdash E_1<E_2\Rightarrow true,s''}\ n_1 < n_1$$

$$\frac{\rho,s\vdash E_1\Rightarrow b_1,s' \quad \rho,s'\vdash E_2\Rightarrow b_2,s''}{\rho,s\vdash E_1<E_2\Rightarrow false,s''}\ n_1 \geq n_2$$

$$\frac{\rho,s\vdash E\Rightarrow true,s'}{\rho,s\vdash \text{not } E\Rightarrow false,s'} \qquad \frac{\rho,s\vdash E\Rightarrow false,s'}{\rho,s\vdash \text{not } E\Rightarrow true,s'}$$

$$\frac{\rho,s\vdash E_1\Rightarrow true,s' \quad \rho,s'\vdash E_2\Rightarrow v,s''}{\rho,s\vdash \text{if } E_1 \text{ then } E_2 \text{ else } E_3\Rightarrow v,s''} \qquad \frac{\rho,s\vdash E_1\Rightarrow false,s' \quad \rho,s'\vdash E_3\Rightarrow v,s''}{\rho,s\vdash \text{if } E_1 \text{ then } E_2 \text{ else } E_3\Rightarrow v,s''}$$

# State & Memory

$$\frac{}{\rho,s\vdash()\Rightarrow\cdot,s}$$

$$\frac{\rho,s\vdash E\Rightarrow v,s'}{\rho,s\vdash\mathrm{ref}\,E\Rightarrow l,[l\mapsto v]s'}\; l\notin s'$$

$$\frac{\rho,s\vdash E\Rightarrow l,s'}{\rho,s\vdash !E\Rightarrow s(l),s'}$$

$$\frac{\rho,s\vdash E_1\Rightarrow v',s' \quad \rho,[l\mapsto v']s'\vdash E_2\Rightarrow v,s''}{\rho,s\vdash x:=E_1\,\mathrm{in}\,E_2\Rightarrow v,s''}\; l=\rho(x)$$

$$\frac{\rho,s\vdash E_1\Rightarrow v',s' \quad \rho,s'\vdash E_2\Rightarrow v,s''}{\rho,s\vdash x:=E_1;E_2\Rightarrow v,s''}$$