Function-Call Efficiency

First: Function calls take constant ($O(1)$) time, so until you’re using the right algorithms and have a critical bottleneck, forget about it.

That said, ML’s “all functions take one argument” can be inefficient in general:

- Create a new $n$-tuple
- Create a new function closure

In practice, implementations optimize common cases. In some implementations, $n$-tuples are faster (avoid building the tuple). In others, currying is faster (avoid building intermediate closures).

In the < 1 percent of code where detailed efficiency matters, you program against an implementation. Bad programmers worry about this stuff at the wrong stage and for the wrong code.

Equivalence

“Equivalence” is a fundamental programming concept

- Code maintenance / backward-compatibility
- Program verification
- Program optimization
- Abstraction and strong interfaces

But what does it mean for an expression (or program) $e_1$ to be “equivalent” to expression $e_2$?
Equivalence I: where?

Context (i.e., “where equivalent”)

- Given where e1 occurs in a program e, replacing e1 with e2 makes a program e’ equivalent to e
- At any point in any program, replacing e1 with e2 makes an equivalent program.

The latter (contextual equivalence) is much more interesting.
For the former, the body of an unused function body is equivalent to everything (that typechecks).

Equivalence II: how?

“how equivalent”

- “partial”: e and e’ are equivalent if they input and output the same data (any limits on input?)
- “total”: partial plus e and e’ have the same termination behavior
- efficiency: e and e’ are totally equivalent and one never takes more than (for example) c times longer than the other (or uses much more space or …)
- syntactic notions: e and e’ differ only in whitespace and comments (for example)

Key notion: what is observable? (memory, clock, REP-loop, file-system, …)

Accounting for “Effects”

Consider whether \( fn \ x \Rightarrow e_1 \) and \( fn \ x \Rightarrow e_2 \) are totally contextually equivalent.

Is this enough? For all environments, \( e_1 \) terminates and evaluates to \( v \) under the environments if and only if \( e_2 \) terminates and evaluates to \( v \) under the environment.

Functions produce values; may also produce (side-) effects. Consider both!

Purely functional languages have fewer/none, but ML is not purely functional.

In real languages, contextual equivalence usually requires many things.
Nonetheless, “equivalence” usually means total contextual equivalence for practical purposes (optimization, reasoning about correctness, etc.).

Syntactic Sugar

When all expressions using one construct are totally equivalent to another more primitive construct, we say the former is “syntactic sugar”.

- Makes language definition easier
- Makes language implementation easier

Examples:

- \( e_1 \) andalso \( e_2 \) (define as a conditional)
- \( \text{if } e_1 \text{ then } e_2 \text{ else } e_3 \) (define as a case)
- \( \text{fun } f \ x \ y = e \) (define with an anonymous function)
More sugar

#_ e is just let val (x,...) = e in x end

If we ignore types, then we have even more sugar:

let val p = e1 in e2 end is just (fn p => e2) e1.

In fact, if we let every program type-check (or just use one big datatype), then a language with just functions and function application is as powerful as ML or Java (in the Turing Tarpit sense).

This language is called “lambda calculus” – we’ll learn a bit more about it later.

Equivalences for Functions

While sugar defines one construct in terms of another, there are also important notions of meaning-preserving changes involving functions and bound variables.

They’re so important that a goal of language design is that a language supports them.

But the correct definitions are subtle.

First example: systematic renaming

Is fn x => e1 equivalent to fn y => e2 where e2 is e1 with every x replaced by y?

Systematic renaming requires care

Is fn x => e1 is equivalent to fn y => e2 where e2 is e1 with every x replaced by y?

What if e1 is y?

What if e1 is fn x => x?

Need caveats: fn x => e1 is equivalent to fn y => e2 where e2 is e1 with every free x replaced by y and y is not free in e1, and no free x occurs within the scope of a binding for y (capture; e.g.:

fn x => let y = 2 in x - y end; see also next slide.)

Note: We can provide a very precise recursive (meta-)definition of free variables in an expression.

Next: Is (fn x => e1) e2 equivalent to e3 where e3 is e1 with every x replaced by e2?

Argument Substitution

Is (fn x => e1) e2 equivalent to e3 where e3 is e1 with every x replaced by e2?

- Every free x (of course).
- A free variable in e2 must not be bound at an occurrence of x.
  (Called “capture”.)
    - Always satisfiable by renaming bound variables.
- Evaluating e2 must have no effects (printing, exceptions, infinite-loop, etc.)
  - Closely tied to the rule that arguments are evaluated to values before function application. (Not true for all languages)
  - In ML, many expressions have no such effects (x, #foo x, ...); much fewer in Java.
- Efficiency? Could be faster or slower. (Why?)
Unnecessary Function Wrapping

A common source of bad style for beginners

Is e1 equivalent to fn x => e1 x?

Sure, provided:

- e1 is effect-free
- x does not occur free in e1

Example:

List.map (fn x => SOME x) 1st
List.map SOME 1st

Summary

We breezed through some core programming-language facts and design goals:

- Definition of equivalence depends on observable behavior
- Syntactic sugar “makes a big language smaller” by \textit{defining} constructs in terms of equivalence
- Notion of free and bound variables crucial to understanding function equivalence.
- Three common forms of function equivalence:
  - Systematic Renaming
  - Argument Substitution
  - Unnecessary Function Wrapping