Data Abstraction
Class outline:

- Lecture 11 follow-ups
- Data abstraction
- Dictionaries
Data abstraction
Data abstractions

Many values in programs are compound values, a value composed of other values.

- A date: a year, a month, and a day
- A geographic position: latitude and longitude

A **data abstraction** lets us manipulate compound values as units, without needing to worry about the way the values are stored.
A pair abstraction

If we needed to frequently manipulate "pairs" of values in our program, we could use a pair data abstraction.

- pair(a, b) constructs a new pair from the two arguments.
- first(pair) returns the first value in the given pair.
- second(pair) returns the second value in the given pair.

couple = pair("Neil", "David")
neil = first(couple) # 'Neil'
david = second(couple) # 'David'
A pair implementation

Only the developers of the pair abstraction needs to know/decide how to implement it.

```python
def pair(a, b):
    # implementation of pair

def first(pair):
    # implementation of first

def second(pair):
    # implementation of second
```

How else could it be implemented?
A pair implementation

Only the developers of the `pair` abstraction needs to know/decide how to implement it.

```python
def pair(a, b):
    return [a, b]

def first(pair):

def second(pair):
```

How else could it be implemented?
A pair implementation

Only the developers of the `pair` abstraction needs to know/decide how to implement it.

```python
def pair(a, b):
    return [a, b]

def first(pair):
    return pair[0]

def second(pair):
    return pair[1]
```

How else could it be implemented?
A pair implementation

Only the developers of the pair abstraction needs to know/decide how to implement it.

```python
def pair(a, b):
    return [a, b]

def first(pair):
    return pair[0]

def second(pair):
    return pair[1]
```

How else could it be implemented?
Rational abstraction
Rational numbers

If we needed to represent fractions exactly...

\[
\frac{\text{numerator}}{\text{denominator}}
\]

We could use this data abstraction:

<table>
<thead>
<tr>
<th>Constructor</th>
<th>rational(n,d)</th>
<th>constructs a new rational number.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selectors</td>
<td>numer(rat)</td>
<td>returns the numerator of the given rational number.</td>
</tr>
<tr>
<td></td>
<td>denom(rat)</td>
<td>returns the denominator of the given rational number.</td>
</tr>
</tbody>
</table>

\[
\text{quarter} = \text{rational}(1, 4) \\
\text{top} = \text{numer}(\text{quarter}) \ # \ 1 \\
\text{bot} = \text{denom}(\text{quarter}) \ # \ 4
\]
# Rational number arithmetic

<table>
<thead>
<tr>
<th>Example</th>
<th>General form</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\frac{3}{2} \times \frac{3}{5} = \frac{9}{10}$</td>
<td>$\frac{n_x}{d_x} \times \frac{n_y}{d_y} = \frac{n_x \times n_y}{d_x \times d_y}$</td>
</tr>
<tr>
<td>$\frac{3}{2} + \frac{3}{5} = \frac{21}{10}$</td>
<td>$\frac{n_x}{d_x} + \frac{n_y}{d_y} = \frac{n_x \times d_y + n_y \times d_x}{d_x \times d_y}$</td>
</tr>
</tbody>
</table>
Rational number arithmetic code

We can implement arithmetic using the data abstractions:

### Implementation

| def mul_rational(x, y):
| return rational(numer(x) * numer(y), denom(x) * denom(y)) |

| def add_rational(x, y):
| (nx, dx) = numer(x), denom(x)
| (ny, dy) = numer(y), denom(y)
| return rational(nx * dy + ny * dx) |

### General form

\[
\frac{n_x}{d_x} \times \frac{n_y}{d_y} = \frac{n_x \times n_y}{d_x \times d_y}
\]

\[
\frac{n_x}{d_x} + \frac{n_y}{d_y} = \frac{n_x \times d_y + n_y \times d_x}{d_x \times d_y}
\]

mul_rational( rational(3, 2), rational(3, 5) )
add_rational( rational(3, 2), rational(3, 5) )
Rational numbers utilities

A few more helpful functions:

```python
def print_rational(x):
    print(numer(x), '/', denom(x))

def rationals_are_equal(x, y):
    return numer(x) * denom(y) == numer(y) * denom(x)

print_rational(rational(3, 2))  # 3/2
rationals_are_equal(rational(3, 2), rational(3, 2))  # True
```
Rational numbers implementation

```python
def rational(n, d):
    """Construct a rational number that represents N/D.""
    return [n, d]

def numer(x):
    """Return the numerator of rational number X.""
    return x[0]

def denom(x):
    """Return the denominator of rational number X.""
    return x[1]
```
Reducing to lowest terms

What's the current problem with...

\[
\text{add\_rational( rational(3, 4), rational(2, 16) )} \quad \# \quad 56/64
\]

\[
\text{add\_rational( rational(3, 4), rational(4, 16) )} \quad \# \quad 64/64
\]
Reducing to lowest terms

What's the current problem with...

```python
add_rational( rational(3, 4), rational(2, 16) )  # 56/64
add_rational( rational(3, 4), rational(4, 16) )  # 64/64
```

\[
\frac{3}{2} \times \frac{5}{3} = \frac{15}{6}
\]

Multiplication results in a non-reduced fraction...

\[
\frac{15}{6} \div \frac{3}{3} = \frac{5}{2}
\]

...so we always divide top and bottom by GCD!
Reducing to lowest terms

What's the current problem with...

```python
add_rational( rational(3, 4), rational(2, 16) )  # 56/64
add_rational( rational(3, 4), rational(4, 16) )  # 64/64
```

\[
\frac{3}{2} \times \frac{5}{3} = \frac{15}{6}
\]

Multiplication results in a non-reduced fraction...

\[
\frac{15}{6} \div \frac{3}{3} = \frac{5}{2}
\]

...so we always divide top and bottom by GCD!

```python
from math import gcd

def rational(n, d):
    """Construct a rational that represents n/d in lowest terms."""
    g = gcd(n, d)
    return [n//g, d//g]
```
Using rationals

User programs can use the rational data abstraction for their own specific needs.

def exact_harmonic_number(n):
    """Return 1 + 1/2 + 1/3 + ... + 1/N as a rational"
    s = rational(0, 1)
    for k in range(1, n + 1):
        s = add_rat(s, rational(1, k))
    return s
Abstraction barriers
## Layers of abstraction

<table>
<thead>
<tr>
<th>Primitive Representation</th>
<th>make_rat() numer() denom()</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data abstraction</td>
<td>add_rat() mul_rat() print_rat() equal_rat()</td>
</tr>
<tr>
<td>User program</td>
<td>exact_harmonic_number()</td>
</tr>
</tbody>
</table>

Each layer only uses the layer above it.
Violating abstraction barriers

What's wrong with...

```python
add_rational( [1, 2], [1, 4] )
```

```python
def divide_rational(x, y):
    return [ x[0] * y[1], x[1] * y[0] ]
```

Violating abstraction barriers

What's wrong with...

```python
add_rational( [1, 2], [1, 4] )
# Doesn't use constructors!
```

```python
def divide_rational(x, y):
    return [ x[0] * y[1], x[1] * y[0] ]
```
Violating abstraction barriers

What's wrong with...

```python
add_rational( [1, 2], [1, 4] )
# Doesn't use constructors!
```

```python
def divide_rational(x, y):
    return [ x[0] * y[1], x[1] * y[0] ]
# Doesn't use selectors!
```
Other rational implementations

The \texttt{rational()} data abstraction could use an entirely different underlying representation.

```python
def rational(n, d):
    def select(name):
        if name == 'n':
            return n
        elif name == 'd':
            return d
    return select

def numer(x):
    return x('n')

def denom(x):
    return x('d')
```

View example usage in PythonTutor
Data types
# Review: Python types

<table>
<thead>
<tr>
<th>Type</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integers</td>
<td>0 -1 0xFF 0b1101</td>
</tr>
<tr>
<td>Booleans</td>
<td>True False</td>
</tr>
<tr>
<td>Functions</td>
<td>def f(x)... lambda x: ...</td>
</tr>
<tr>
<td>Strings</td>
<td>&quot;pear&quot; &quot;I say, &quot;hello!&quot;&quot;</td>
</tr>
<tr>
<td>Ranges</td>
<td>range(11) range(1, 6)</td>
</tr>
<tr>
<td>Lists</td>
<td>[] [&quot;apples&quot;, &quot;bananas&quot;]</td>
</tr>
<tr>
<td></td>
<td>[x**3 for x in range(2)]</td>
</tr>
</tbody>
</table>
Dictionaries
Dictionaries

A **dict** is a mutable mapping of key-value pairs

```python
states = {
    "CA": "California",
    "DE": "Delaware",
    "NY": "New York",
    "TX": "Texas",
    "WY": "Wyoming"
}
```

**Queries:**

```python
>>> len(states)

>>> "CA" in states

>>> "ZZ" in states
```
Dictionaries

A **dict** is a mutable mapping of key-value pairs

```python
states = {
    "CA": "California",
    "DE": "Delaware",
    "NY": "New York",
    "TX": "Texas",
    "WY": "Wyoming"
}
```

Queries:

```python
>>> len(states)
5

>>> "CA" in states
True

>>> "ZZ" in states
False
```
Dictionaries

A **dict** is a mutable mapping of key-value pairs

```python
states = {
    "CA": "California",
    "DE": "Delaware",
    "NY": "New York",
    "TX": "Texas",
    "WY": "Wyoming"
}
```

Queries:

```python
>>> len(states)
5

>>> "CA" in states
True

>>> "ZZ" in states
```

Dictionaries

A **dict** is a mutable mapping of key-value pairs

```python
states = {
    "CA": "California",
    "DE": "Delaware",
    "NY": "New York",
    "TX": "Texas",
    "WY": "Wyoming"
}
```

**Queries:**

```python
>>> len(states)
5

>>> "CA" in states
True

>>> "ZZ" in states
False
```
Dictionary selection

```python
words = {
    "más": "more",
    "otro": "other",
    "agua": "water"
}
```

Select a value:

```python
>>> words["otro"]

>>> first_word = "agua"
>>> words[first_word]

>>> words["pavo"]

>>> words.get("pavo", "")
```
Dictionary selection

```python
words = {
    "más": "more",
    "otro": "other",
    "agua": "water"
}
```

Select a value:

```python
>>> words["otro"]
'other'

>>> first_word = "agua"
>>> words[first_word]

>>> words["pavo"]

>>> words.get("pavo", "")
```
Dictionary selection

```python
words = {
    "más": "more",
    "otro": "other",
    "agua": "water"
}

Select a value:

```python
>>> words["otro"]
'other'

```python```python
>>> first_word = "agua"
>>> words[first_word]
'water'

```python```python
>>> words["pavo"]

```python```python
>>> words.get("pavo", "")
```
Dictionary selection

```python
words = {
    "más": "more",
    "otro": "other",
    "agua": "water"
}
```

Select a value:

```python
>>> words["otro"]
'other'

>>> first_word = "agua"
>>> words[first_word]
'water'

>>> words["pavo"]
KeyError: pavo

>>> words.get("pavo", "")

```
Dictionary selection

```python
words = {
    "más": "more",
    "otro": "other",
    "agua": "water"
}
```

Select a value:

```python
>>> words["otro"]
'other'

>>> first_word = "agua"
>>> words[first_word]
'water'

>>> words["pavo"]
KeyError: pavo

>>> words.get("pavo", "")
''
```
Dictionary rules

- A key **cannot** be a list or dictionary (or any mutable type)
- All keys in a dictionary are distinct (there can only be one value per key)
- The values can be any type, however!

```python
spiders = {
    "smeringopus": {
        "name": "Pale Daddy Long-leg",
        "length": 7
    },
    "holocnemus pluchei": {
        "name": "Marbled cellar spider",
        "length": (5, 7)
    }
}
```
Dictionary iteration

insects = {'spiders': 8, 'centipedes': 100, 'bees': 6}
for name in insects:
    print(insects[name])

What will be the order of items?
insects = {
    "spiders": 8, 
    "centipedes": 100, 
    "bees": 6
}
for name in insects:
    print(insects[name])

What will be the order of items?

8 100 6

Keys are iterated over in the order they are first added.
Dictionary comprehensions

General syntax:

```python
{key: value for <name> in <iter exp>}
```

Example:

```python
{x: x*x for x in range(3,6)}
```
Exercise: Prune

def prune(d, keys):
    """Return a copy of D which only contains key/value pairs
    whose keys are also in KEYS.
    >>> prune({"a": 1, "b": 2, "c": 3, "d": 4}, ["a", "b", "c"])
    {'a': 1, 'b': 2, 'c': 3}
    """
Exercise: Prune (Solution)

```python
def prune(d, keys):
    """Return a copy of D which only contains key/value pairs whose keys are also in KEYS.
    >>> prune({"a": 1, "b": 2, "c": 3, "d": 4}, ["a", "b", "c"])
    {'a': 1, 'b': 2, 'c': 3}
    """
    return {k: d[k] for k in keys}
```
Exercise: Index

def index(keys, values, match):
    """Return a dictionary from keys k to a list of values v for which
    match(k, v) is a true value.
    
    >>> index([7, 9, 11], range(30, 50), lambda k, v: v % k == 0)
    {7: [35, 42, 49], 9: [36, 45], 11: [33, 44]}
    """
Exercise: Index (solution)

def index(keys, values, match):
    """Return a dictionary from keys k to a list of values v for which
    match(k, v) is a true value.
    """
    return {k: [v for v in values if match(k, v)] for k in keys}
# Nested data

| Lists of lists | `[ [1, 2], [3, 4] ]` |
| Dicts of dicts | `{"name": "Brazilian Breads", "location": {"lat": 37.8, "lng": -122}}` |
| Dicts of lists | `{"heights": [89, 97], "ages": [6, 8]}` |
| Lists of dicts | `[{"title": "Ponyo", "year": 2009}, {"title": "Totoro", "year": 1993}]` |
Python Project of The Day!
NVDA


Technologies used: Python, eSpeak, Sonic, etc. (Github repository)