Search Algorithms: Object-Oriented Implementation (Part C)

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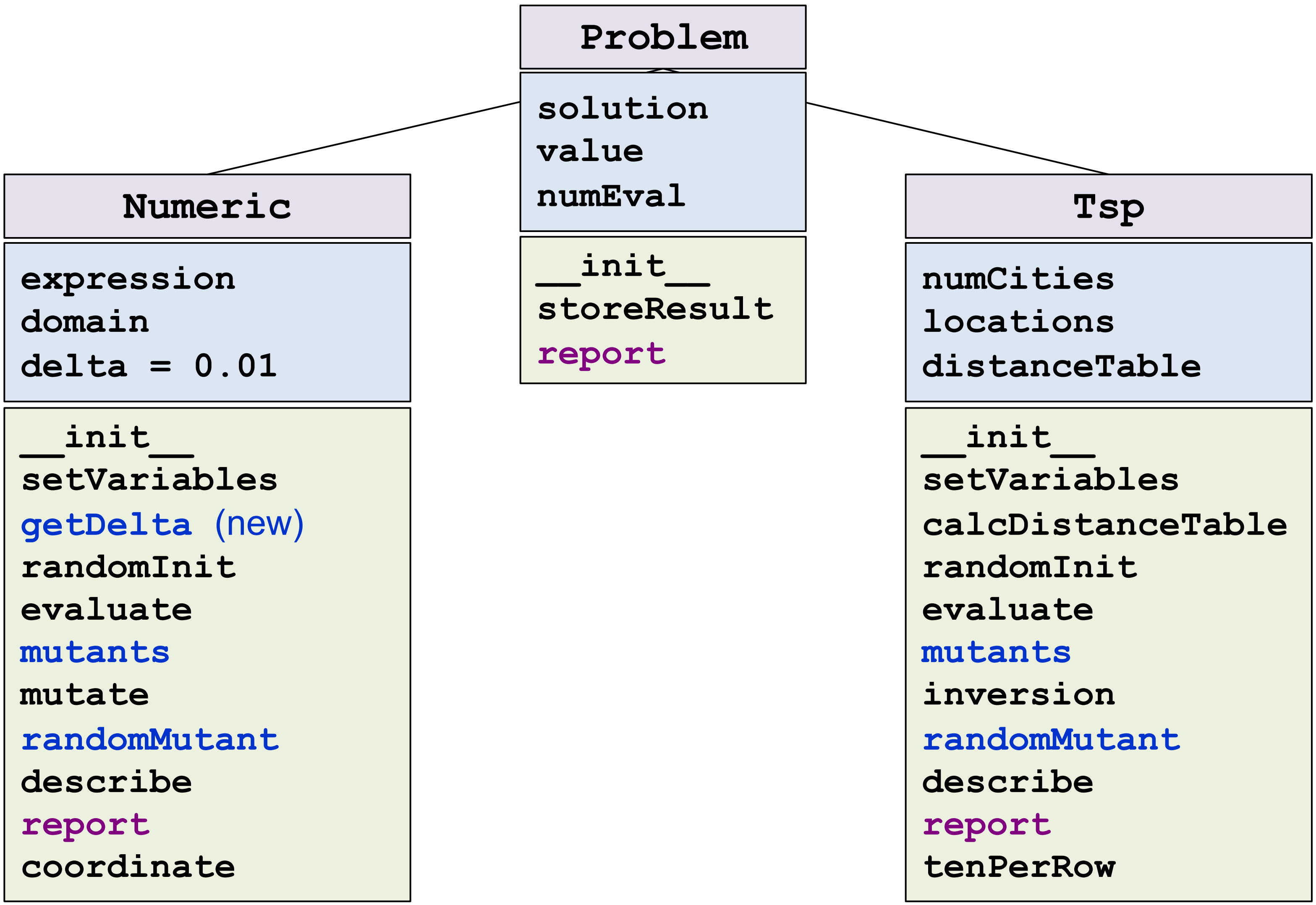
Defining ‘Problem’ Class

- We define a hierarchy of classes whose base class is named as **`Problem`**
  - Information about the problem to be solved can be stored in an organized fashion
  - Codes of the same purposes but with different problem-specific implementations can be organized nicely under this class hierarchy
  - The result of search can also be handled nicely depending on the type of problem solved
- **`Problem`** has two subclasses **`Numeric`** and **`Tsp`**
  - Functions in the ‘numeric’ module become methods of **`Numeric`**
  - Similarly, those in the ‘tsp’ module become methods of **`Tsp`**

Defining 'Problem' Class



Defining 'Problem' Class

- Some functions are renamed after migration:
  - **`createProblem`** → **`setVariables`**
  - **`describeProblem`** → **`describe`**
  - **`displayResult`** → **`report`**

- The subclass **`Numeric`** has three variables for storing specifics about the problem:
  - **`expression`**: function expression of a numerical optimization problem
  - **`domain`**: lower and upper bounds of each variable of the function
  - **`delta`**: step size of axis-parallel mutation

Defining 'Problem' Class

- **`delta`** takes the role of **`DELTA`** that was previously the named constant of the 'numeric' module
  - **`delta`** is referred to by **`mutants`** and **`randomMutant`**
  - Its value is preset to 0.01 for the time being for convenience
  - The method **`getDelta`** is newly made for being used by the **`displaySetting`** function of the main program when displaying the value of **`delta`**

- The subclass **`Tsp`** also has three variables:
  - **`numCities`**: number of cities
  - **`locations`**: coordinates of city locations in a 100×100 square
  - **`distanceTable`**: matrix of distances of every pair of cities

Defining 'Problem' Class

- Both **`Numeric`** and **`Tsp`** have the **`setVariables`** method that reads in the specifics of the problem to be solved and stores them in the relevant class variables
  - It is renamed from its previous version **`createProblem`**
  - Unlike **`createProblem`**, **`setVariables`** does not return anything

- Notice that the functions **`mutants`** and **`randomMutant`** can also be converted to methods of both **`Numeric`** and **`Tsp`** classes just like **`mutate`** or **`inversion`**
  - **`mutants`** appears in both SAHC-N and SAHC-T
  - **`randomMutant`** appears in both FCHC-N and FCHC-T
- This makes the main programs simpler and thus easier for later unification

Defining ‘Problem’ Class

- The base class **`Problem`** has three variables for storing the result of search:
  - **`solution`**: final solution found by the search algorithm
  - **`value`**: its objective value
  - **`numEval`**: total number of evaluations taken for the search

  However, the way to report the result is different depending on the type of problem solved

- The values of the two variables **`solution`** and **`value`** are set by the **`storeResult`** method that is called by the search algorithms
  - Now the search algorithms do not have the **`return`** statement

Defining 'Problem' Class

- The value of **`numEval`** is initially 0 and incremented whenever the **`evaluate`** method is called
  - Previously, reporting the value of the global variable **`NumEval`** was done by **`displayResult`** of both 'numeric' and 'tsp' modules
    - Recall that **`NumEval`** appeared in duplicate in both modules
  - Now, printing **`numEval`** is done by the **`report`** method

Defining ‘Problem’ Class

- `report` (previously `displayResult`) is defined in both the base class and the subclasses
  - `report` in the base class prints `numEval` that is a common information to both the subclasses
    - The one in the base case handles general information and is inherited to the subclasses
  - `report` in each subclass prints further information specific to the problem type
  - To inherit a method of a superclass, it should be stated explicitly (e.g., `Problem.report(self)`)

- We can see that object-oriented programming provides us with the opportunity to organize codes in a way easier to maintain

Defining 'Problem' Class

- `Numeric` and `Tsp` have many methods of the same names but with different implementations
  - Polymorphism allows us to write codes that look the same regardless of the type of problem to be solved
  - E.g., `evaluate` of `Numeric` and `evaluate` of `Tsp` are of the same name but are implemented differently depending on the type of problem to be solved (numerical optimization or TSP)

- By introducing the classes and taking advantage of polymorphism, we will eventually be able to unite the main programs of different search algorithms into a single program
  - Duplications among different main programs can be avoided

Defining ‘Problem’ Class

- We store **`Problem`** in a separate file named ‘problem.py’
  - ‘random.py’ and ‘math.py’ that were imported to the previous modules should now be imported to the ‘problem.py’ file
  - Each main program needs to import either **`Numeric`** or **`Tsp`** from the ‘problem.py’ file

Changes to the Main Program

- It is the **`main`** function that creates an instance of **`Problem`** object (**`p = Numeric()`** or **`p = Tsp()`**)
  - Then, the **`setVariables`** method (**`p.setVariables`**) is executed to store the corresponding values in the relevant class variables
  - Previously this was done by the function **`createProblem`**

- After creating problem **`p`**, the **`main`** function calls the search algorithm with **`p`** as its argument
  - The search algorithm calls the methods such as **`randomInit`**, **`evaluate`**, and **`mutants`** to conduct the search and these methods refer to the relevant class variables when executed

Changes to the Main Program

- The **`main`** function, after running the search algorithm, makes calls to relevant functions or methods to show the specifics of the problem solved (**`p.describe`**), to display the settings of the search algorithm (**`displaySetting`**), and then to display the result (**`p.report`**)

- There were two versions of **`mutants`** for the steepest-ascent hill climbing, one for numeric optimization and the other for TSPs
  - They are now migrated to the **`Numeric`** and **`Tsp`** classes
- Similarly, **`randomMutant`** of the first-choice hill climbing are migrated to the **`Numeric`** and **`Tsp`** classes, too

- The functions **`displaySetting`** and **`bestOf`** still remain in the main program because they are tied with the search algorithms used rather than the types of the problems solved

Adding Gradient Descent

- Gradient descent is the same as the steepest-ascent except the way a next point is created from the current point
  - Steepest ascent generates m neighbors from which to select a successor to move to
    - m evaluations are needed
  - Gradient descent computes gradient at the current point and apply the gradient update rule to move to a next point
    - n evaluations are needed to calculate partial derivatives in all the dimensions, where n is the dimension of the objective function
    - One additional evaluation is needed to evaluate the next point obtained by applying the update rule using the gradient
- Gradient descent is applicable only to numerical optimization

Adding Gradient Descent

- Two variables are newly added to the **`Numeric`** subclass:
  - **`alpha`**: update rate for gradient descent
    - Set to a default value of 0.01 for the time being
    - Referenced by the method **`takeStep`**
  - **`dx`**: size of the increment used when calculating derivative
    - Set to a default value of 10^{-4} for the time being
    - Referenced by the method **`gradient`**

$$\boldsymbol{x} \leftarrow \boldsymbol{x} - \alpha \nabla f(\boldsymbol{x})$$

$$\frac{df(x)}{dx} = \lim_{dx \to 0} \frac{f(x+dx) - f(x)}{dx}$$

Adding Gradient Descent

- Also, five methods are newly added to the **`Numeric`** subclass:
  - **`takeStep(self, x, v)`**:
    - Computes the gradient (**`gradient`**) of the current point **`x`** whose objective value is **`v`**

$$\nabla f(\boldsymbol{x}) = \left(\frac{\partial f(\boldsymbol{x})}{\partial x_1}, \frac{\partial f(\boldsymbol{x})}{\partial x_2}, \cdots, \frac{\partial f(\boldsymbol{x})}{\partial x_d} \right)^T$$

    - Makes a copy of **`x`** and changes it to a new one by applying the gradient update rule as long as the new one is within the domain (**`isLegal`**)

$$\left(\boldsymbol{x} - \alpha \nabla f(\boldsymbol{x})\right)_i = x_i - \alpha \frac{\partial f(\boldsymbol{x})}{\partial x_i}$$

Adding Gradient Descent

- **`gradient(self, x, v)`**
  - Calculates partial derivatives at **`x`**

$$\frac{\partial f(\boldsymbol{x})}{\partial x_i} = \frac{f(\boldsymbol{x}') - f(\boldsymbol{x})}{\delta}$$

$$\boldsymbol{x}' = (x_1, \ldots, x_{i-1}, x_i + \delta, x_{i+1}, \ldots, x_d)^T$$

  - Returns the gradient $\nabla f(\boldsymbol{x})$
- **`isLegal(self, x)`**
  - Checks if **`x`** is within the domain
- **`getAlpha(self)`**
- **`getDx(self)`**

- **`getAlpha`** and **`getDx`** are called from **`displaySetting`** of the main program when reporting the update rate and the increment size for calculating derivative