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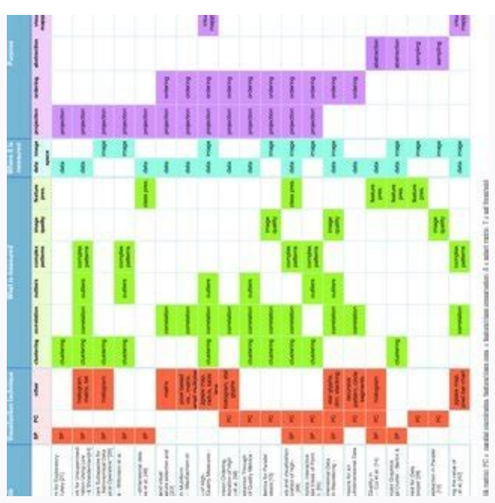

Object-Oriented Programming with C++ and Java

Debasis Samanta
Associate Professor
School of Information Technology
Indian Institute of Technology Kharagpur
Kharagpur

PHI Learning Private Limited
New Delhi-110001
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JMatch: Iterable Abstract Pattern Matching for Java

Jed Liu and Andrew C. Myers

Computer Science Department
Cornell University, Ithaca, New York

Abstract. The JMatch language extends Java with *iterable abstract pattern matching*, pattern matching that is compatible with the data abstraction features of Java and makes iteration abstractions convenient. JMatch has ML-style deep pattern matching, but patterns can be abstract; they are not tied to algebraic data constructors. A single JMatch method may be used in several modes; modes may share a single implementation as a boolean formula. Modal abstraction simplifies specification and implementation of abstract data types. This paper describes the JMatch language and its implementation.

1 Introduction

Object-oriented languages have become a dominant programming paradigm, yet they still lack features considered useful in other languages. Functional languages offer expressive pattern matching. Logic programming languages provide powerful mechanisms for iteration and backtracking. However, these useful features interact poorly with the data abstraction mechanisms central to object-oriented languages. Thus, expressing some computations is awkward in object-oriented languages.

In this paper we present the design and implementation of JMatch, a new object-oriented language that extends Java [GJS96] with support for *iterable abstract pattern matching*—a mechanism for pattern matching that is compatible with the data abstraction features of Java and that makes iteration abstractions more convenient. This mechanism subsumes several important language features:

- convenient use and implementation of iteration abstractions (as in CLU [L+81], ICON [GHK81], and Sather [MOSS96].)
- convenient run-time type discrimination without casts (for example, Modula-3's `typecase` [Nel91])
- deep pattern matching allows concise, readable deconstruction of complex data structures (as in ML [MTHF90], Haskell [Jon99] and Cyclone [JMG+02].)
- multiple return values
- views [Wad87]
- patterns usable as first-class values [PGPN96,FB97]

Email: `jed@cs.washington.edu`, `andru@cs.cornell.edu`. Jed Liu is now at the University of Washington, Seattle, WA.

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Programming and Data Structures Recall that abstraction is the idea of separating what something is from how it works, by separating interface from implementation. Previously, we saw procedural abstraction, which applies abstraction to computational processes. With procedural abstraction, we use functions based on their signature and documentation without having to know details about their definition. The concept of abstraction can be applied to data as well. An abstract data type (ADT) separates the interface of a data type from its implementation, and it encompasses both the data itself as well as functionality on the data. An example of an ADT is the string type in C++, used in the following code: string str1 = "hello"; string str2 = "jello"; cout 0 // MODIFIES: *tri // EFFECTS: Scales the sides of the Triangle by the factor s. void Triangle_scale(Triangle *tri, double s) { tri->a *= s; tri->b *= s; tri->c *= s; } Our naming convention for functions that are part of a C-style ADT is to prepend the function name with the name of the ADT, Triangle in this case. The first parameter is a pointer to the actual Triangle object the function works on. If the object need not be modified, we declare the pointer as a pointer to const. The following demonstrates how to use the Triangle ADT functions: int main() { Triangle t1 = { 3, 4, 5 }; Triangle_scale(&t1, 2); // sides are now 6, 8, 10 cout b = b_in; tri->c = c_in; } int main() { Triangle t1; Triangle_init(&t1, 3, 4, 5); Triangle_scale(&t1, 2); cout side2 = b_in; tri->angle = std::acos((std::pow(a_in, 2) + std::pow(b_in, 2) - std::pow(c_in, 2)) / (2 * a_in * b_in)); } // REQUIRES: tri points to a valid Triangle // EFFECTS: Returns the first side of the given Triangle. double Triangle_side1(const Triangle *tri) { return tri->side1; } // REQUIRES: tri points to a valid Triangle // EFFECTS: Returns the second side of the given Triangle. double Triangle_side2(const Triangle *tri) { return tri->side2; } // REQUIRES: tri points to a valid Triangle // EFFECTS: Returns the third side of the given Triangle. double Triangle_side3(const Triangle *tri) { return std::sqrt(std::pow(tri->side1, 2) + std::pow(tri->side2, 2) - 2 * tri->side1 * tri->side2 * std::acos(tri->angle)); } // REQUIRES: tri points to a valid Triangle // EFFECTS: Returns the perimeter of the given Triangle. double Triangle_perimeter(const Triangle *tri) { return Triangle_side1(tri) + Triangle_side2(tri) + Triangle_side3(tri); } // REQUIRES: tri points to a valid Triangle; s > 0 // MODIFIES: *tri // EFFECTS: Scales the sides of the Triangle by the factor s. void Triangle_scale(Triangle *tri, double s) { tri->side1 *= s; tri->side2 *= s; } Here, we have added accessor or getter functions for each of the sides, allowing a user to obtain the side lengths without needing to know implementation details. Even within the ADT itself, we have used Triangle_side3() from within Triangle_perimeter() to avoid code duplication. The REQUIRES clauses of the ADT functions make a distiction between Triangle objects and valid Triangle objects. The former refers to an object that is of type Triangle but may not have been properly initialized, while the latter refers to a Triangle object that has been initialized by a call to Triangle_init(). Except for Triangle_init(), the ADT functions all work on valid Triangles. Now that we have a full definition of a C-style ADT, we adhere to the following convention for working with one: the user of a C-style ADT may only interact with the ADT through its interface, meaning the functions defined as part of the ADT's interface. The user is generally prohibited from accessing struct member variables directly, as those are implementation details of the ADT. This convention also holds in testing an ADT, since tests should only exercise the behavior of an ADT and not its implementation. When designing an abstract data type, we must build a data representation on top of existing types. Usually, there will be cases where the underlying data representation permits combinations of values that do not make sense for our ADT. For example, not every combination of three doubles represents a valid triangle – a double may have a negative value, but a triangle may not have a side with negative length. The space of values that represent valid instances of a triangle abstraction is a subset of the set of values that can be represented by three doubles, as illustrated in Figure 39. Figure 39 Representation invariants define the valid subset of the values allowed by the data representation of an ADT.¶ Thus, when designing an ADT, we need to determine the set of values that are valid for the ADT. We do so by specifying representation invariants for our ADT, which describe the conditions that must be met in order to make an object valid. For a triangle represented as a double for each side, the following representation invariants must hold: The length of each side must be positive. The triangle inequality must hold: the sum of any two sides must be strictly greater than the remaining side. Often, we document the representation invariants as part of the ADT's data definition: // A triangle ADT. struct Triangle { double a; double b; double c; // INVARIANTS: a > 0 && b > 0 && c > 0 && // a + b > c && a + c > b && b + c > a }; We then enforce the invariants when constructing or modifying an ADT object by encoding them into the REQUIRES clauses of our functions. We can use assertions to check for them as well, where possible: // REQUIRES: tri points to a Triangle object; // each side length is positive (a > 0 && b > 0 && c > 0); // the sides meet the triangle inequality // (a + b > c && a + c > b && b + c > a) // MODIFIES: *tri // EFFECTS: Initializes the triangle with the given side lengths. void Triangle_init(Triangle *tri, double a, double b, double c) { assert(a > 0 && b > 0 && c > 0); // positive lengths assert(a + b > c && a + c > b && b + c > a); // triangle inequality tri->a = a; tri->b = b; tri->c = c; } // REQUIRES: tri points to a valid Triangle; s > 0 // MODIFIES: *tri // EFFECTS: Scales the sides of the Triangle by the factor s. void Triangle_scale(Triangle *tri, double s) { assert(s > 0); // positive lengths tri->a *= s; tri->b *= s; tri->c *= s; } As mentioned above, we adhere to the convention of only interacting with an ADT through its interface. Usually, this means that we do not access the data members of an ADT in outside code. However, occasionally we have the need for an ADT that provides no more functionality than grouping its members together. Such an ADT is just plain old data (POD) 1, without any functions that operate on that data, and we define its interface to be the same as its implementation. 1 We use the term "plain old data" in the generic sense and not as the specific C++ term. C++ has a generalization of POD types called aggregates. Technically, the Person struct we saw last time is an aggregate but not a POD. What we mention here for POD types generally applies to aggregates as well. The following is an example of a Pixel struct used as a POD: // A pixel that represents red, green, and blue color values. struct Pixel { int r; // red int g; // green int b; // blue }; int main() { Pixel p = { 255, 0, 0 }; cout phi; } We can run our existing test cases to get some confidence that our code is working. In addition, the process of coming up with a data representation, representation invariants, and function definitions often suggests new test cases. For instance, the following test cases check that the representation invariants are met when Polar_init() is passed values that don't directly meet the invariants: // Tests initialization with a negative radius. TEST(test_negative_radius) { Polar p; Polar_init(&p, -5, 225); ASSERT_EQUAL(Polar_radius(&p), 5); ASSERT_EQUAL(Polar_angle(&p), 45); } // Tests initialization with an angle >= 360. TEST(test_big_angle) { Polar p; Polar_init(&p, 5, 405); ASSERT_EQUAL(Polar_radius(&p), 5); ASSERT_EQUAL(Polar_angle(&p), 45); } Given our initial implementation, these test cases will fail. We can attempt to fix the problem as follows: void Polar_init(Polar* p, double radius, double angle) { p->r = std::abs(radius); // set radius to its absolute value p->phi = angle; if (radius < 0) { // rotate angle by 180 degrees if radius p->phi = p->phi + 180; // was negative } } Running our test cases again, we find that both test_negative_radius and test_big_angle still fail: the angle value returned by Polar_angle() is out of the expected range. We can fix this as follows: void Polar_init(Polar* p, double radius, double angle) { p->r = std::abs(radius); // set radius to its absolute value p->phi = angle; if (radius < 0) { // rotate angle by 180 degrees if radius p->phi = p->phi + 180; // was negative } p->phi = std::fmod(p->phi, 360); // mod angle by 360 } Now both test cases succeed. However, we may have thought of another test case through this process: // Tests initialization with a negative angle. TEST(test_negative_angle) { Polar p; Polar_init(&p, 5, -45); ASSERT_EQUAL(Polar_radius(&p), 5); ASSERT_EQUAL(Polar_angle(&p), 315); } Unfortunately, this test case fails. We can try another fix: void Polar_init(Polar* p, double radius, double angle) { p->r = std::abs(radius); // set radius to its absolute value p->phi = angle; if (radius < 0) { // rotate angle by 180 degrees if radius p->phi = p->phi + 180; // was negative } p->phi = std::fmod(p->phi, 360); // mod angle by 360 if (p->phi < 0) { // rotate negative angle by 360 p->phi += 360; } } Our test cases now all pass. Previously, we learned about the standard input and output streams, as well as file streams. We examine the relationship between streams more closely now, as well as how to write unit tests using string streams. A stream is an abstraction over a source of input, from which we can read data, or a sink of output, to which we can write data. Streams support the abstraction of character-based input and output over many underlying resources, including the console, files, the network, strings, and so on. In C++, input streams generally derive from istream 3. We will see what this means specifically when we look at inheritance and polymorphism in the future. For our purposes right now, this means that we can pass different kinds of input-stream objects to a function that takes in a reference to an istream. Similarly, output streams generally derive from ostream, and we can pass different kinds of output-stream objects to a function that takes in a reference to an ostream. Figure 42 Relationships between different kinds of input and output streams.¶ 3 The istream type is actually an alias for basic_istream, which is an input stream that supports input using the char type. The same goes for ostream and basic_ostream. To write data into an output stream, we use the insertion operator

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