Olympiads in Informatics, 2009, Vol. 3, 101–111

Representational Means for Tasks in Informatics

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Abstract. Either a task in informatics reflects any image in mind or not; references (hints) to any reality can take place in the task. This reality can relate to local circumstances, the host town, the host state or to sponsors of the informatics olympiad (at the same time, the task should be "culturally neutral"). By our experience of conducting informatics olympiads in Kyrgyzstan since 1985 and submitting tasks to preceding IOIs we classify such references, survey such tasks and propose some techniques to make tasks more interesting and original and to attract different sponsors. Alternative types of tasks are also discussed.

Key words: olympiads in informatics, tasks, reality, local circumstances.

1. Survey of Ways to Generate Tasks and the Aim of Paper

Some authors including Diks *et al.* (2007, 2008) have thoroughly examined the phases of the task preparation process in such a way that it may be applied not only to informatics but to other sciences as well. Regarding informatics itself, among other ideas and classifications, Burton and Hiron (2008) offered two opposite ways to create a good task: "To wrap an abstract task inside a good story" and "To look around and to take inspiration from real things". Let us denote these ways as $A \to R$, *from_algorithm_(or from_abstract)_to_reality* and $R \to A$, *from_reality_to_algorithm*. In (Pankov, 2008) we reviewed ways to generate task ideas based on actions in real and imaginary spaces and called such tasks *natural.* In other words, we suppose that the good task should create an image in the mind of the contestant and that is why we prefer the way $R \to A$. In our experience, even problems from abstract mathematical spaces (Weeks, 1985) can be presented in a *natural* way in programming tasks. What is more interesting – such *natural* presentations are accepted relatively easy by children, giving them the opportunity to get knowledge about complex objects from early childhood.

The aim of this paper is to illustrate the process of taking any real object and creating a task for an informatics olympiad involving this object.

The second section offers classifications of objects, their presentations and ways to involve them in tasks, with some examples.

The third section proposes various types of tasks within these classifications including both generalizations of our tasks (Pankov *et al.*, 2000; Pankov *et al.*, 2003; Pankov and Oruskulov, 2007; Pankov, 2008), reminders of some known tasks (from our point of view) and some new types – "slow algorithms", graphical tasks and tasks of the "black box" type.

We shall not consider the full procedure of creating a task with all restrictions, tests etc. because it is not an aim of this paper and it was considered in details in (Diks *et al.*, 2007; Dicks *et al.*, 2008), Burton and Hiron, 2008) and other publications. We shall give either a brief description of "environment" (under the denotation "Task fragment") or a brief text of a task with a hope that it can be brought up to full-grown.

2. Classifications

2.1. *Classification of the References to Objects in the Text of Task*

In this section we propose to classify "representing" tasks by the explicitness of the definition of the real object:

– RE) explicit definition with the corresponding description of the task; we shall not mention such definitions;

– RI) implicit definition (in such a way that the contestant can guess about it; in national olympiads such guessing can also be involved into the task);

– RM) mixed definition: the name and some features of the object are defined explicitly and the other features are to be guessed from the description.

The second classification in this subsection is by the adequacy of the real object and its image. We shall estimate it by levels of adequacy from A1 (the lowest) to A5 (the highest). In the $A \to R$ case, the adequacy is usually lower.

2.2. *Classification of Objects*

This subsection shows various types of natural objects that can be used in informatics olympiad tasks.

O1) Host country of the olympiad.

O2) Host city of the olympiad.

O3) Host University of the olympiad.

O4) Sponsor of the olympiad.

O5) Local Sights.

O6) Local History, Customs, Events (but tasks at international olympiads should be "culturally neutral", so most tasks will be given at national olympiads).

O7) Location, Local Geography.

O8) National language.

O9) Animals including the current year's animal in the Oriental 12-year-cycle calendar: Mouse, Cow (2009), Tiger, Hare or Cat, Dragon, Snake, Horse, Sheep, Monkey, Hen, Dog, Pig. By tradition, each NOI in Kyrgyzstan has one task of this type.

O10) Numbers. By the tradition of some olympiads in informatics and mathematics, one set of tasks contains the number of the current year. Also, other numbers relating to jubilees or sponsors of the olympiad can be involved.

2.3. *Classification of Images of Objects*

This subsection classifies the images of the tasks objects:

I1) String constant (name, e-mail, URL-address etc.). This is the simplest way.

I2) Graphical presentation of string constant, mentioned in I1.

I3) Graphical image (flag, insignia, logo).

REMARK. If the graphical image is complex and consists of curved lines etc. then it is possible to simplify if for the purpose of a task.

Task fragment 1 (O1). The description of the Kyrgyzstan national flag (see Pankov and Oruskulov, 2007, Task 4): A solar disk with forty beams is placed in the center of the red rectangular background . . . (A4)

In graphical tasks with a small image of the flag we use the simplified version: a yellow circle on a red background (A1).

I4) Location (Address) of the object.

I5) Structure of the object. Classical but not so interesting

Task fragment 2 (O2, A1). A rectangular grid as a map of the streets of the host city (see Task fragment 23 below).

I6) Activity of the object (the most interesting but the most difficult case). The simplest example could be:

Task fragment 3 (including O9). Rules of the possible motion of “actors” (see (Pankov, 2008)).

3. Examples of Tasks

In addition to common types of tasks we offer the following types of tasks, mentioned briefly in (Pankov and Oruskulov, 2007):

T1) Acceleration of an algorithm. An algorithm is given explicitly, but works too slowly. Write a program yielding same results in acceptable time (traditionally, CPU time less than 1 second). At a national olympiad, if this algorithm is classified O1, O2, O6 or O8 then an additional question may be: What does such algorithm mean and where it can be used?

T2) Graphical tasks (with non-formal scoring, convenient for national olympiads). In our opinion, such tasks meet the Statute S1.7 of the IOI regulations “to bring the discipline of Informatics to the attention of young people". In our experience, such tasks make olympiads more attractive for sponsors and reflect state and national features. Sponsors (usually from the IT industry) see their logos and attributes made more recognizable among young people.

T3) "Black Box" tasks. We refer to black box as a procedure with unknown content. Additional information is given as "genotype" ("inner") or "phenotype" ("external"). The task of the contestant is to write a procedure giving the same results; Its text can differ but results must coincide.

In the following examples we shall not describe restrictions. The final version of the task, with corresponding restrictions, can be derived from the advice in (Burton and Hiron, 2008), section 5 *"Improving the task"*.

REMARK. In our opinion, tasks themselves ought to contain text only; graphical images should be in examples only. We shall write most tasks briefly: "find ..." besides of "write a program finding ..." etc. Some tasks built by the means of the above techniques were published in (Pankov *et al.*, 2000; Pankov *et al.*, 2003; Pankov and Oruskulov, 2007; Pankov, 2008).

3.1. *Text Processing with String Constants*

3.1.1. *Tasks about "reading"*

Task 4 (O2, classical). A (long) word W of capital Latin letters is given. How many times can the word PLOVDIV be read from left to right in W (ignoring the other letters)?

Task 5 (O2, classical). Given a two-dimensional array of capital Latin letters P, L, O, V, D, I. How many times can the word PLOVDIV be read in the array, moving only right and down (without ignoring letters)?

Task 6 (O2, Generalization of Tasks 1 and 2). Given a graph (or a directed graph) with some capital Latin letter assigned to each of its vertices. How many paths (directed paths) in the graph carry the word PLOVDIV:

Task 6A: as a sub-word; *Task* 6B: as a sub-sequence; if a vertex can be passed several times by the path.

Task 7 (O2). Given a graph (or a directed graph) with some capital Latin letter assigned to each of its vertices. Find the minimal number of paths in the graph such that the concatenation of the carried paths words is the word PLOVDIV? A vertex can be passed several times.

Task 8 (O1 or O2). Given a graph (or a directed graph) with some capital Latin letter assigned to each of its vertices. Find the length of the shortest path that carries the word (*Task* 8A: PLOVDIV or *Task* 8B: BURGAS)?

REMARK. The principal difference between these words is that all letters in the word "BURGAS" are different, so any "standard" algorithm can be "wrapped" into this word, meanwhile the word "PLOVDIV" demands the modification of such an algorithm.

3.1.2. *Tasks about "transforming"*

Task 9 (O2). Given a (long) word W of capital Latin letters. How many sub-words at least should be deleted from W to get the word PLOVDIV?

EXAMPLE. Input: PLDODVDPLOVXDIV. Output: 2 ["PLDODVD" and "X" to be deleted].

Task 10 (O2). Given a graph (or a directed graph), with capital Latin letters assigned to some or all of its vertices. How many letters at least must be changed to obtain a path that carries the word PLOVDIV?

It is seen that there are many transformation possibilities (deleting, inserting, changing, gluing and their combinations).

There is no inherent difference between the two types of tasks mentioned above. A task on complex "reading" can be presented as a task on simple "transforming" but the range of input data must be different; thousands and even millions of characters are acceptable for "reading" tasks but dozens or hundreds for "transforming".

Task 11 (O8). Words in the Kyrgyz language, containing vowels A, E, I, O, U, and Y, can only have either consecutive same vowels or the following pairs of consecutive different vowels: AY, YA, EI, IE, OU, and UA. Given is a "word" W containing more than one vowel. At least how many vowels must be erased from W to obtain a new word, the sub-sequence of vowels of which contain only permited pairs of consecutive vowels?

EXAMPLE 1. Input: KYRGYZSTAN. Output: 0.

EXAMPLE 2. Input: TOOFEIGUZAEEWYQ. Output: 4 [OOEIUAEEY → OOUAY, and the correct "word" is TOOFGUZAWYQ].

REMARK. 1) Actually, there are eight vowels in Kyrgyz language (including OE and UE). 2) Other Turkic languages have similar rules.

3.2. *Graphical Images of String Constants*

Giving formal descriptions of letters as geometric objects is very difficult. For example, the letters L, O, V, I in their simplest geometrical forms (two segments, a circle, a vertical segment) are easy for description but letters P and D are not so easy. The abbreviation "IOI" itself is very convenient for geometrical presentations and transformations.

Task 12 (O3). Given are some points with integer coordinates. How many (at least) points must be added to them to obtain a configuration with symmetry (in their simplest form) of the type of the letter K (horizontal mirror symmetry); of the letter N (central symmetry); of the letter U (vertical mirror symmetry? (KNU is an abbreviation of Kyrgyz National University).

3.3. *Geometrical Images*

3.3.1. *Uncertainty of Restoring by Non-complete Information*

The main difficulty in such tasks is treating the boundaries of the domains.

Preface to the following Tasks 13, 14, 15: “The Bulgarian flag consists of white, green and red (from up to down) horizontal strips of equal size. The ratio of the horizontal size to the vertical one is 5:3”.

Task 13 (O1, O9). In the night, a fire-fly can detect its exact position by means of the GPS navigation system and it knows that it is near a big Bulgarian flag. The fire-fly can switch on its lamp only a restricted number of times. Let all corners of the colored strips of the Flag have even integer coordinates and the fire-fly switches on its lamp at points with odd integer coordinates.

Given is a list of colored points as triples of two odd integer numbers and one of the four letters: W (white), G (green), R (red) and D (darkness, i.e., on / off of the Flag). At least two of W, G, R are presented. Find

Task 13A: the greatest possible size of the Flag; *Task* 13B: the boundaries of the center of the Flag.

3.3.2. *Composing*

Let a “block” be a rectangle of size 1×2 (vertical).

Task 14 (O1). A child has blocks of different colors: W – white, WG – half white and half green (one square of the block is white and the other is green), G – green, GR – half green and half red and R – red. Given are five non-negative integer numbers W, WG, G, GR and R.

Task 14A. Find the greatest possible size of a Bulgarian flag which the child can make using these blocks. [The given numbers are large].

Task 14B. At least how many additional blocks must the child make and paint in order to compose a Bulgarian flag? [Some of the given numbers are too small].

Task 15 (O1). Given ten non-negative integer numbers $W1$, $WG1$, $G1$, $GR1$, $R1$, $W2$, $WG2$, $G2$, $GR2$, $R2$ denoting the numbers of colored blocks kept by two children – the first and second child respectively. At least how many blocks of any color must be moved between children to give each of them the opportunity to compose their own Bulgarian flag (two flags could be of different sizes)?

Another version of Task 15:

Task 16 (O1). Given N triples of non-negative integer numbers ($W[k], G[k], R[k]$), denoting the numbers of colored squares of equal size kept by the kth child, $k = 1, 2, \ldots, N$. At least how many squares must be moved between children to give each of them the opportunity to compose their own Bulgarian flag? (Different flags could be of different sizes)?

Example of an implicit presentation of the Bulgarian flag.

Task 17 (O1, T3, RI). Given is a function $C(X, Y)$ that transforms the couples of integers $(X, Y), 1 \leqslant X \leqslant 1000, 1 \leqslant Y \leqslant 1000$ to letters. Its text is invisible to the contestant:

```
{ C=''D'';
  if X > 20 then
  { if 100 > X then
    { if Y > 500 then {if 520 > Y then C=''R''};
      if Y > 519 then {if 539 > Y then C=''G''};
      if Y > 539 then {if 560 > Y then C=''W''};
    };
   };
}.
```

Task 17A. "Inner" information: Variables C, X and Y are integer constants within the interval [1..1000], ">" signs are always between a letter and a number (or vice versa), fewer than 10 statements "if ... then ..." are used and arithmetical operations are not used in the text.

Task 17B. "External" information:

If $X1 < X2 < X3$, $X3 - X1 < 10$ and $C(X1, Y) = C(X3, Y)$ then $C(X2, Y) = C(X1, Y)$.

If $Y1 < Y2 < Y3$, $Y3 - Y1 < 10$ and $C(X, Y1) = C(X, Y3)$ then $C(X, Y2) = C(X, Y1)$.

(Continuation of both tasks) By means of calling and analyzing the function $C(X$,Y)

1) Write a function named $FC(X, Y)$ that gives the same results in a CPU time less than 0.001 second. Its size must be less than 500 bytes. (To prevent including a 1000×1000 array into the function).

2) What does the function $C(X, Y)$ mean?

REMARK. Such a task can be solved by calling the function several times and analyzing the results or by writing a corresponding program (or sequence of programs).

Example of implicit presentation of another object.

Task 18. DISTANCES (O1, O6, RI). Given a natural number N $(13 \leqslant N \leqslant 50)$, and two natural numbers L, M ($1 \leqslant L < M \leqslant 100$, $M \leqslant 5 * L$). Your task is to choose N points with integer coordinates on a plane in such a way that the number of different distances between them, being not less than L and not greater than *M,* is as large as possible.

Input: A file with one line containing the integer numbers N, L, and M.

Output: A file with:

1) one line with the numbers N, L, M;

2) N lines with the list of chosen N points. Each line has to contain a label of the point (integer from 1 to N), its x-coordinate, and its y-coordinate (integers between 1 and 10000). All points must be different.

3) One line with the number of pairs of points being in distances within the interval $[L, M]$.

Scoring: if your output data is correct (the criteria of correctness must be here) then your score for one test case is

(1+ 9*(NumPairsInYourAnswer/NumPairsInBestAnswer) 2) rounded down.

REMARK. Despite of square root in the formula for the distance, this task operates on integer numbers, without rounding.

Task 19 (O1, T2, RI, for Kyrgyzstan). Given is the following algorithm which builds some image:

{ K *is integer;* U, V, X, Y *are real;* X: = 20; Y: = 0;
{ *for* K *from* (−3) *to* 4
{ U: = 0.7 * (X−Y); V: = 0.7 * (X+Y);
if K = 4 *then* { U: = 20; V: = 0}
else {*draw line*(3.4*K−1.7, 5−|K|)−(3.4*K, 8−|K|)−(3.4*K+1.7, 5−|K|)}
draw segment (X, Y)−(U, V); X: = U; Y: = V}
draw circle with center (0, 8) *and radius* 2;
}.

A) Choose a scale and show the image on the screen (save this file).

B) Correct the image according to its kind (save the second file).

C) Complete the image with one or two elements at your will according to its kind (save the third file).

Tests:

A) There should be a regular octagon, seven (mountain) peaks within it and a little circle on the middle of the highest peak.

B) The contestants were to guess, that the item A) contains elements of Kyrgyzstan State insignia. The circumscribed octagon must be replaced by a circle. The little circle denotes the sun (behind the mountains). Hence the bottom arch of this circle (within the middle peak) must be erased.

C) Possible elements of the insignia: beams of the sun; the inscription "KYRGYZ REPUBLIC" (in Cyrillic); hints on a surface of the lake (Issyk-Kul); a closer and lower mountain ridge; White Falcon; ears or cotton.

3.4. *Behavior of Animals*

Task fragment 20 (O9, I6). In Korea (host of IOI'2002) the naughtiness of the *cheong-gaeguri*, a small frog, is legendary. A frog always jumps through the paddy in a straight line, with every hop the same length. Different frogs can jump with different hop lengths and in different directions on the intersection points of a grid . . .

We hope that the following task yields new characteristic of a graph.

Task 21 (O9, I6). Given a connected graph of (narrow, sufficiently long) holes underground. One of its vertices is the entrance. A family of given number of mice (with the plan of the graph) is going to install themselves. But firstly they want to examine all the graph (beginning from and returning to the entrance) to discuss results. Find the minimal time necessary for this purpose. The velocity of a mouse is one edge per minute. A mouse cannot turn back within an edge.

REMARK. The answer is not obvious even for a dendrite graph.

Task 22 (O9, O7, I6). Let a lake looks like an isosceles triangle; the basis of the triangle (northern coast) is 190 km and height (width of the lake) is 60 km. A village is located on northern coast of the lake, 20 km from the western corner. A horse runs with speed of 20 km/h and swims with speed of 10 km/h. Given a point on the coast of the lake, find the minimal time to reach the village from this point with an accuracy of 0.01 hour.

Using real numbers for tasks at informatics olympiads was considered in details in (Opmanis, 2006).

REMARK. This task, motion from south-western coast to a village across Issyk-Kul lake, reflects a historic fact. In commemoration of this feat, the village was named Toru-Aigyr (Bay Stallion).

3.5. *Structure*

We propose the following improvement of *Task fragment* 2.

Task fragment 23 (O2, A2). Let the streets in the virtual city of Plovdiv form a rectangular grid: X and Y are integers, $0 \leqslant X \leqslant N$, $-N \leqslant Y \leqslant N$, $Y \neq 0$. The line $Y = 0$ is the Maritsa river. It can be crossed by the seven bridges only, their x-coordinates are $B = \text{trunk}(N/8)$, $2 * B, 3 * B, \ldots, 7 * B$. Given the integer N, $8 \leqslant N \leqslant 1000\ldots$

3.6. *Customs, History, Activity*

A brilliant example of the history with activity is the task “Fish” given at the practice session of IOI’2007.

Task 24. PILLAGERS (O6, I6, A5). Towns with some amounts of fish are situated on a long (straight) coastline. If a town ships F tons of fish to another town which is D km away then hungry pillagers descending from the mountains take $\min(F, D)$ tons. Each tourist needs 1 ton of fish. Given the positions of all towns and amounts of fish in all towns, find the largest integer Y such that each town can accommodate at least Y tourists.

In (Pankov, 2008) it was proposed the following task:

Task fragment 25 (O7, I6). See Fig. 1. *Regions that hosted finals of the NOI* (15 towns) in the paper (Dagiene and Skupiene, 2007).

Two friends with bicycles decided to make photos of these towns for the illustrated history of NOIs. The array of distances (in hours!) between some pairs of these 16 points is given. Write a program calculating the minimal number of days for such enterprise.

3.7. *Graphs*

The following technique transforms a string constant into an abstract graph.

Task 26 (O1, O2, O3, ...). Given is the constant word W, for example "PLOVDIV_IN_BULGARIA" (19 characters; the number and scope of the characters may be increased arbitrarily). Given two integers $1 \leqslant X < Y \leqslant 19$, find the necessary number of steps to reach $W[X]$ from $W[Y]$. At each step one may pass either to an adjacent character or to an identical character at other place in the word.

EXAMPLE. Input: $X = 4; Y = 13$. Output: 4 [$W[X] =$"V"; W[Y]="U"; way: V-O-L-L-U].

3.8. *Numbers as an Aim*

The following two tasks are very simple but demonstrate "accelerating of a given algorithm" and the fitting of an object.

Task 27 (O10, A5). Given the following

Algorithm Year_Mult;
Integer I, J, K, N; *Boolean* Mult = *true*;
{ *output* ("Enter a natural number N, 1 <= N <= 2009"); *input* (N);
for I = N *to* 2009 { *for* J = N *to* 2009 { *for* K = N *to* 2009
{*if* I*J*K = 2009 *then* {Mult = false; *output*("Mult"; I, J, K)} } } };
if Mult *then output*("Mult_Nothing");
}.

Task 28 (O10, A2). Given the following

Algorithm Year_Add;
Integer I, J, K, N, Add = 0;
{ *output* ("Enter a natural number N, 1 <= N <= 2009"); *input* (N);
for I = N *to* 2009 { *for* J = N *to* 2009 { *for* K = N *to* 2009
{*if* I+J+K = 2009 *then* Add = Add+1} } };
output("Add = "; Add)
}.

(Both tasks:) Write programs implementing fast algorithms that calculate the same results in a CPU time of 1 second.

REMARK. Task 27 is an "apt" use of the number (A5) because its successful solution demands finding prime factors of 2009 itself. Task 28 is a "common" use of the number (A2) because 2009 can be changed to another large number.

4. Conclusion

This paper gives an overview and examples of the ideas that can be used to create competitive tasks for national and international olympiads in informatics.

The tasks built in such a way that would be interesting for young people and attractive for prospective sponsors. Also, such tasks with high level of adequacy (A4, A5) give less advantage to experienced participants because they would not be able to use known algorithms immediately. On the other hand, tasks of (O6) and (T1, T2, T3) are not used at IOIs. So, after conducting the Kygyzstani NOI (usually in March) we select candidates from schoolchildren who have demonstrated good results on set of tasks containing traditional types used at previous IOIs.

We also advise, before visiting any country, to learn more about its language, state symbols, history, geography, and customs.

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