Automated Structural Testing with PathCrawler.
A Tutorial

Examples.

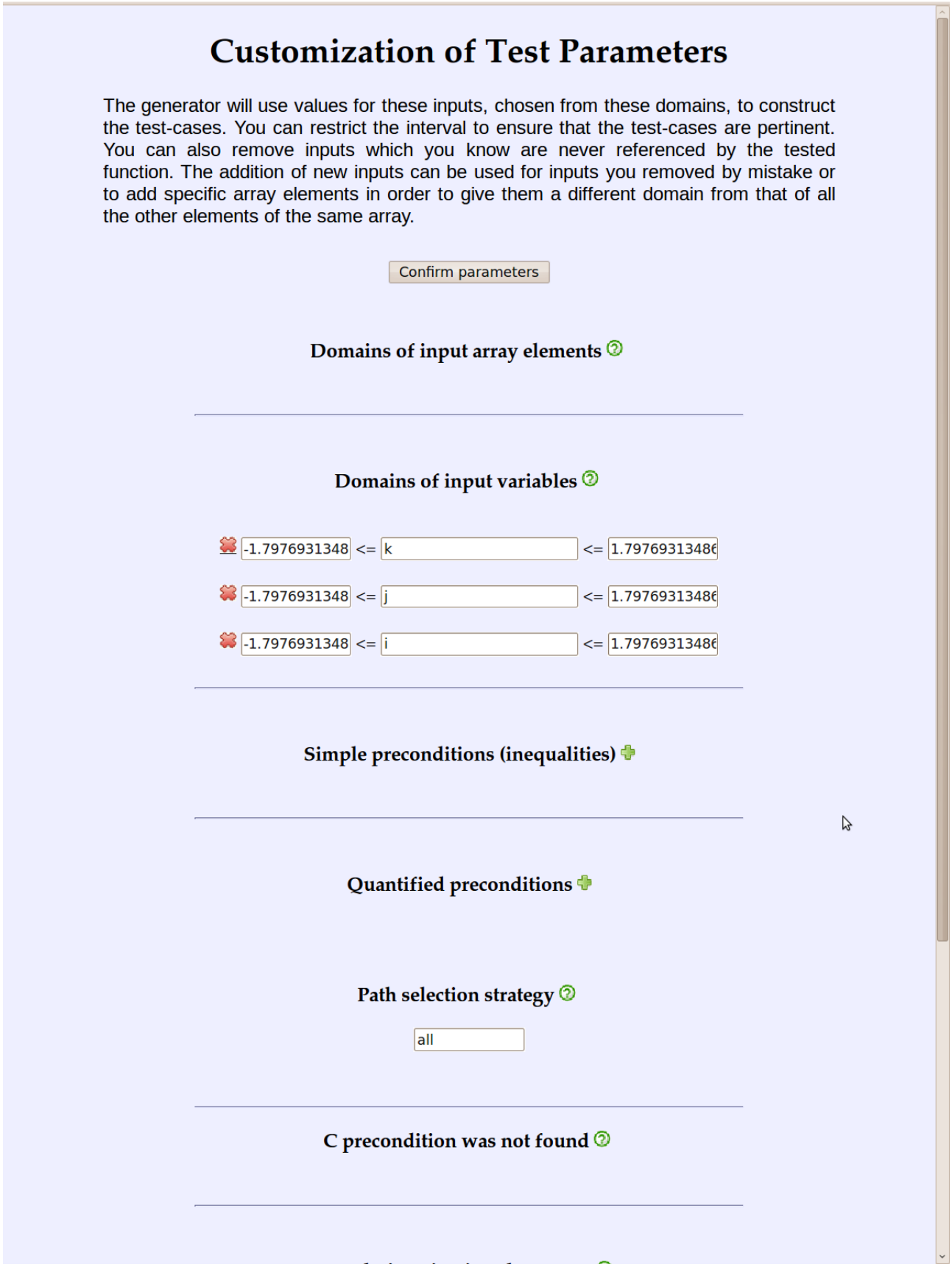
Nicky.WILLIAMS@cea.fr, Nikolai.KOSMATOV@cea.fr
CEA, LIST, Software Safety Lab
Saclay (Paris), France

2012

Example 1. Function under test: `Tritype`

```
/* Should return the type of the triangle
   which has sides of these lengths.
   3 = not a triangle
   2 = equilateral triangle
   1 = isoceles triangle
   0 = other triangle
*/
int Tritype(double i, double j, double k){
  int trityp = 0;
  if (i < 0.0 || j < 0.0 || k < 0.0)          // line 10
    return 3;
  if (i + j <= k || j + k <= i || k + i <= j) // line 12
    return 3;
  if (i == j) trityp = trityp + 1;            // line 14
  if (i == k) trityp = trityp + 1;            // line 15
  if (j == k) trityp = trityp + 1;            // line 16
  if (trityp >= 2)                            // line 17
      trityp = 2;
  return trityp;
}
```

Default test parameters:



Example 2. Function under test: `Tritype`

```
/* Should return the type of the triangle
   which has sides of these lengths.

   2 = equilateral triangle
   1 = isoceles triangle
   0 = other triangle
*/
int Tritype(double i, double j, double k){
  int trityp = 0;
//  if (i < 0.0 || j < 0.0 || k < 0.0)        // line 10
//    return 3;
//  if (i + j <= k || j + k <= i || k + i <= j)//line 12
//    return 3;
  if (i == j) trityp = trityp + 1;            // line 14
  if (i == k) trityp = trityp + 1;            // line 15
  if (j == k) trityp = trityp + 1;            // line 16
  if (trityp >= 2)                            // line 17
      trityp = 2;
  return trityp;
}
```

Default test parameters: see Example 1

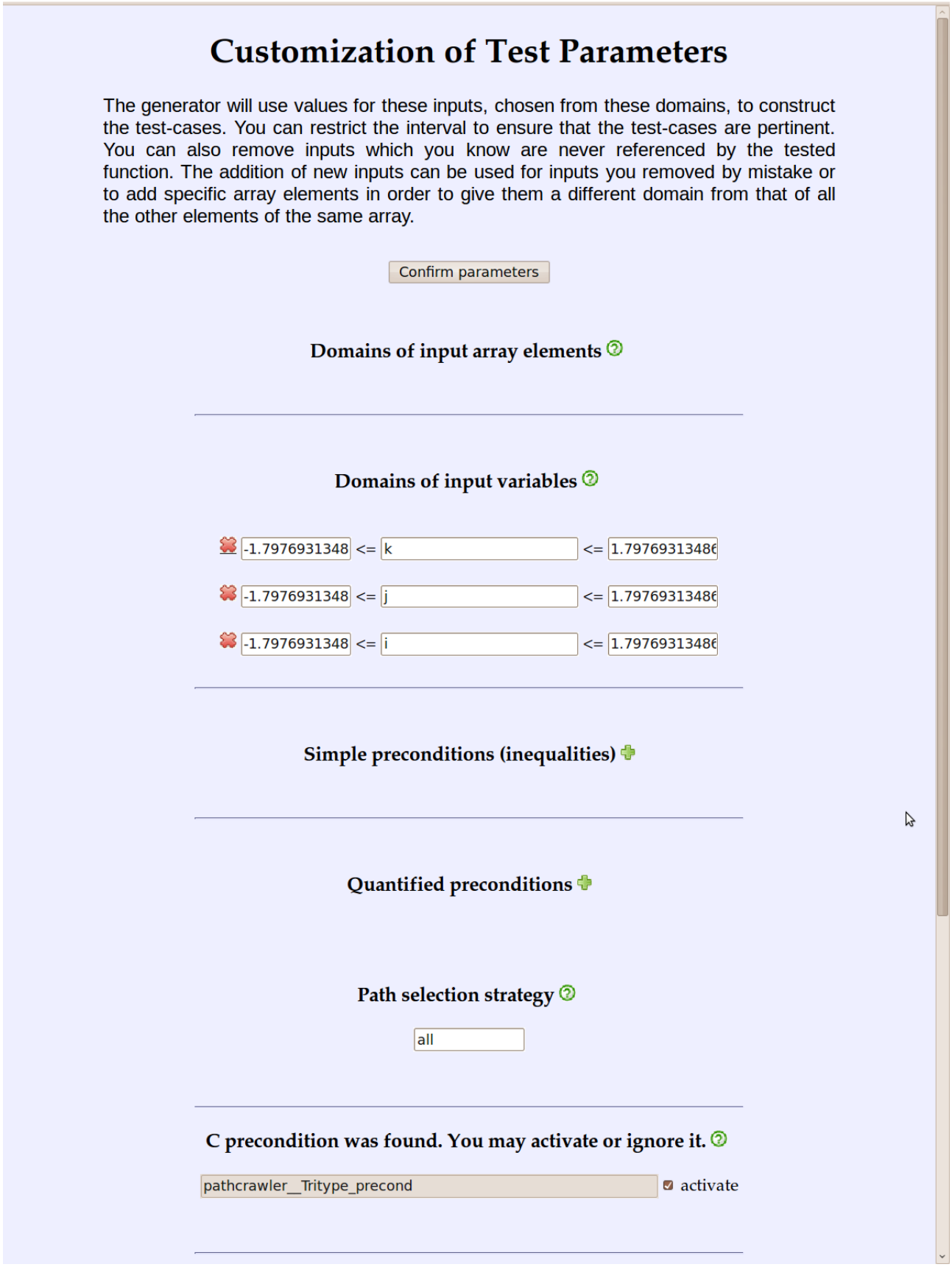
Example 4. Function under test: `Tritype`

```
/* Should return the type of the triangle
   which has sides of these lengths.

   2 = equilateral triangle
   1 = isoceles triangle
   0 = other triangle
*/
int Tritype(double i, double j, double k){
  int trityp = 0;
//  if (i < 0.0 || j < 0.0 || k < 0.0)        // line 10
//    return 3;
//  if (i + j <= k || j + k <= i || k + i <= j)//line 12
//    return 3;
  if (i == j) trityp = trityp + 1;            // line 14
  if (i == k) trityp = trityp + 1;            // line 15
  if (j == k) trityp = trityp + 1;            // line 16
  if (trityp >= 2)                            // line 17
      trityp = 2;
  return trityp;
}

int Tritype_precond(double i, double j, double k){
  if (i < 0.0 || j < 0.0 || k < 0.0)          // line 23
    return 0;
  if (i + j <= k || j + k <= i || k + i <= j) // line 25
    return 0;
  return 1;
}
```

Default test parameters:



Example 5. Function under test: `Merge`

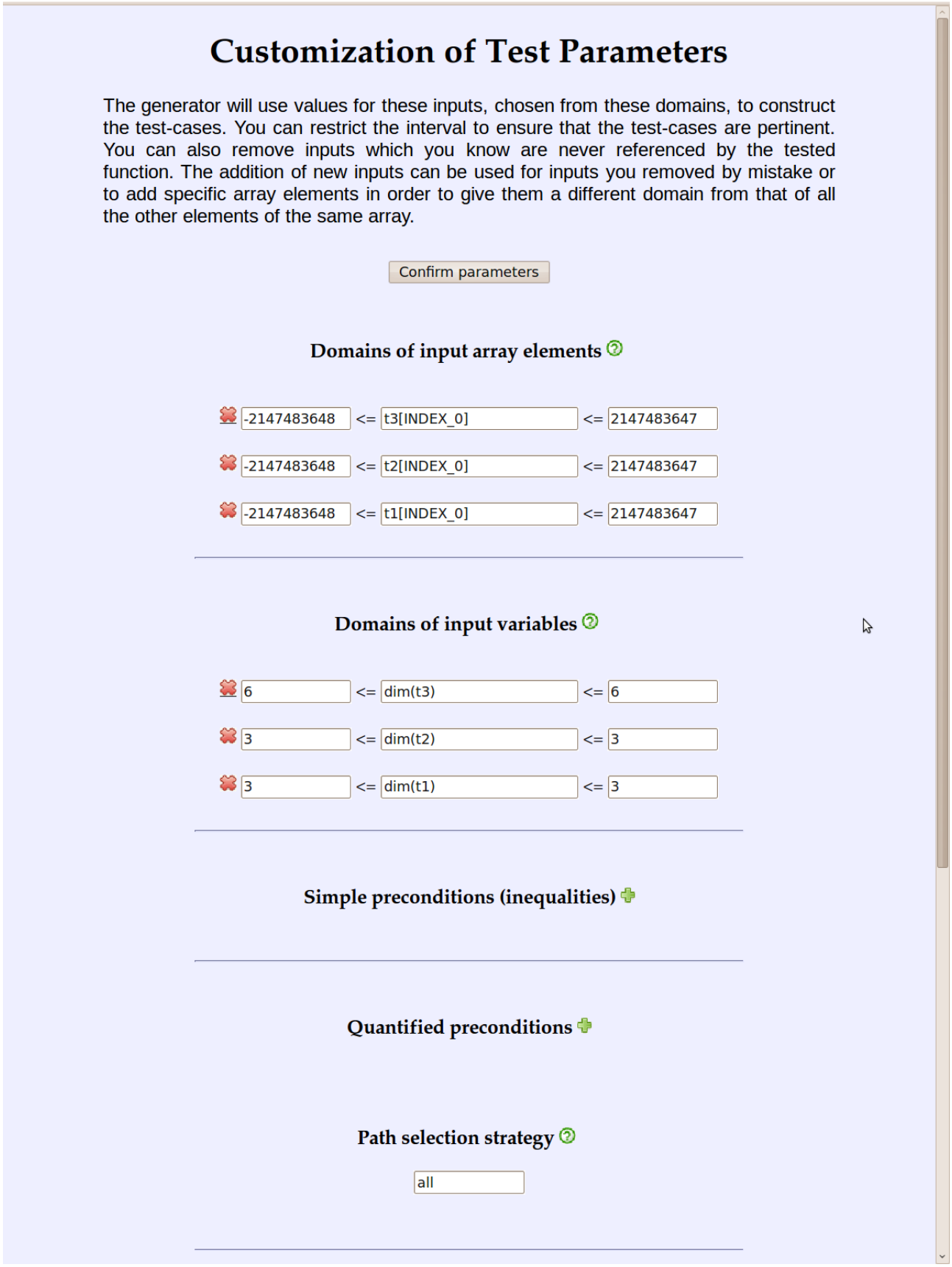
```
/* Should copy all the elements
   of ordered arrays t1 and t2
   into the ordered array t3 */

void Merge(int t1[3], int t2[3], int t3[6]) {

  int i = 0, j = 0, k = 0 ;

  while (i < 3 && j < 3) { // line 09
    if (t1[i] < t2[j]) {   // line 10
      t3[k] = t1[i];
      i++;
    }
    else {
      t3[k] = t2[j];
      j++;
    }
    k++ ;
  }
  while (i < 3) {          // line 20
    t3[k] = t1[i];
    i++;
    k++;
  }
  while (j < 3) {          // line 25
    t3[k] = t2[j];
    j++;
    k++;
  }
}
```

Default test parameters:



Example 7. Function under test: `Merge`

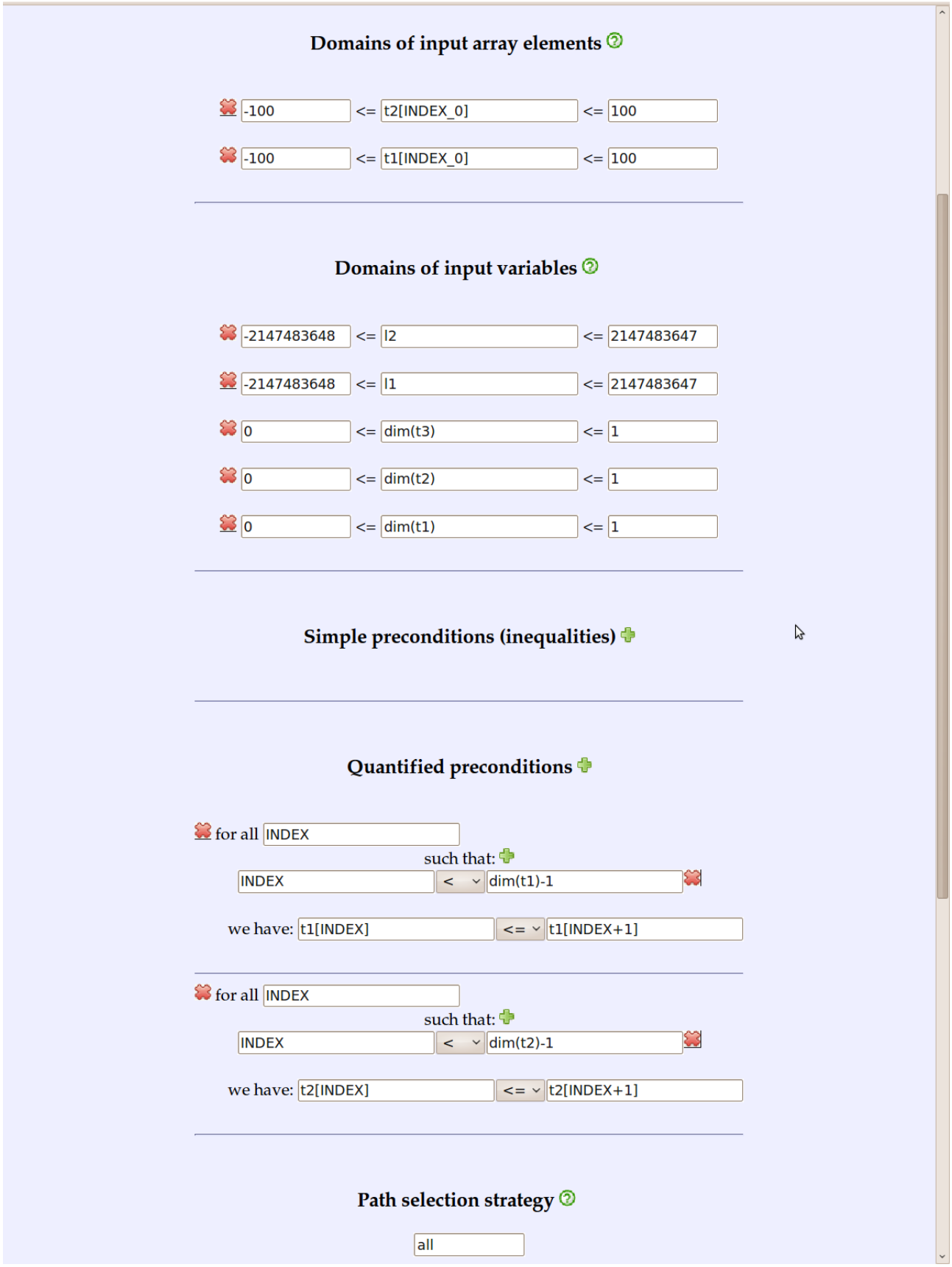
```
/* Should copy all the elements
   of ordered arrays t1 and t2
   of lengths l1 and l2
   into the ordered array t3 */
void Merge (int t1[], int t2[], int t3[], int l1, int l2) {

  int i = 0, j = 0, k = 0 ;

  while (i < l1 && j < l2) { // line 09
    if (t1[i] < t2[j]) {     // line 10
      t3[k] = t1[i];
      i++;
      }
    else {
      t3[k] = t2[j];
      j++;
      }
    k++;
    }
  while (i < l1) {           // line 20
    t3[k] = t1[i];
    i++;

    }
  while (j < l2) {           // line 25
    t3[k] = t2[j];
    j++;
    k++;
    }
}
```

Predefined test parameters:



Example 10a. Function under test: `Merge` (see Example 7), Predefined test parameters:

Oracle:

```
void oracle_Merge(
  int Pre_t1[], int t1[],
  int Pre_t2[], int t2[],
  int Pre_t3[], int t3[],
  int Pre_l1, int l1,
  int Pre_l2, int l2)
{
  int i, j, n1, n2, n3;
  int l3 = l1 + l2;
  int l3moins1 = l3 -1;

  for (i = 0; i < l3moins1; i++) {
    if (t3[i] > t3[i+1]) {
      pathcrawler_verdict_failure(); /* line 14: t3 not ordered */
      return;
    }
  }
  pathcrawler_verdict_success();
}
```

Example 10b. Function under test: `Merge` (see Example 7)

Predefined test parameters: see Example 10a.

Oracle:

```
void oracle_Merge(
  int Pre_t1[], int t1[],
  int Pre_t2[], int t2[],
  int Pre_t3[], int t3[],
  int Pre_l1, int l1,
  int Pre_l2, int l2)
{
  int i, j, n1, n2, n3;
  int l3 = l1 + l2;
  int l3moins1 = l3 -1;

  for (i = 0; i < l3moins1; i++) {
    if (t3[i] > t3[i+1]) {
      pathcrawler_verdict_failure(); /* line 14: t3 not ordered */
      return;
    }
  }
  i = 0;
  while (i < l3) {
    /* count occurences of this element in t3 */
    n3 = 1;
    while (i < l3moins1 && t3[i + 1] == t3[i]) {
      i++;
      n3++;
    }
    /* count occurences of this element in  t1 */
    n1 = 0;
    for (j = 0; j < l1; j++) {
      if (t1[j] == t3[i])
        n1++;
    }
    /* count occurences of this element in  t2 */
    n2 = 0;
    for (j = 0; j < l2; j++) {
      if (t2[j] == t3[i])
        n2++;
    }
    /* compare */
    if (n3 != (n1 + n2)) {
      pathcrawler_verdict_failure(); /* line 40: t3 does not have the
correct number of occurrences of all elements */
      return;
    }
    i++;
  }
  pathcrawler_verdict_success();
}
```

Example 10c. Function under test: `Merge` (see Example 7)

Predefined test parameters: see Example 10a.

Oracle:

```
void oracle_Merge(
  int Pre_t1[], int t1[],
  int Pre_t2[], int t2[],
  int Pre_t3[], int t3[],
  int Pre_l1, int l1,
  int Pre_l2, int l2)
{
  int i, j, n1, n2, n3;
  int l3 = l1 + l2;
  int l3moins1 = l3 -1;

  for (i = 0; i < l1; i++) {
    if (Pre_t1[i] != t1[i]) {
      pathcrawler_verdict_failure(); /* line 14: t1 modified */
      return;
    }
  }

  for (i = 0; i < l2; i++) {
    if (Pre_t2[i] != t2[i]) {
      pathcrawler_verdict_failure(); /* line 21: t2 modified */
      return;
    }
  }

  for (i = 0; i < l3moins1; i++) {
    if (t3[i] > t3[i+1]) {
      pathcrawler_verdict_failure(); /* line 28: t3 not ordered */
      return;
    }
  }
  i = 0;
  while (i < l3) {
    /* count occurences of this element in t3 */
    n3 = 1;
    while (i < l3moins1 && t3[i + 1] == t3[i]) {
      i++;
      n3++;
    }
    /* count occurences of this element in  t1 */
    n1 = 0;
    for (j = 0; j < l1; j++) {
      if (t1[j] == t3[i])
        n1++;
    }
    /* count occurences of this element in  t2 */
    n2 = 0;
    for (j = 0; j < l2; j++) {
      if (t2[j] == t3[i])
        n2++;
    }
    /* compare */
    if (n3 != (n1 + n2)) {
      pathcrawler_verdict_failure(); /* line 54: t3 does not have the correct number of
occurrences of all elements */
      return;
    }
     i++;
  }
  pathcrawler_verdict_success();
}
```

Example Uninit. Function under test: `uninit_var`

```
int uninit_var(int a[3], int b[3]) {
  int i, k;
  for(i=0; i<2; i++) {     // line 3
      if(a[i] == 0)        // line 4
     return 0;
      if(a[i] != a[i+1])   // line 6
        k = 0;
      else
        if(k == 2)         // line 9
       return 0;
      while(b[k] != a[i])  // line 11
          if(k == 2)       // line 12
         return 0;
          else
            k++;
      }
  return 1;
}
```

Example UC. Function under test: `Bsearch`

```
/* Should return 1 if x is an element of ordered array A */
int Bsearch( int A[8], int x) // tested function
{
  int low, high, mid, found ;

  low = 0 ;
  high = 7 ;
  found = 0 ;
  while( high > low )                    // line 09
    { mid = (low + high) / 2 ;

      if( x == A[mid] )                  // line 12
         found = 1;

      if( x > A[mid] )                   // line 15
        low = mid + 1 ;
      else
        high = mid - 1;
    }
  mid = (low + high) / 2 ;

  if( ( found != 1)  && ( x == A[mid]) ) // line 22
    found = 1;

  return found ;
}
```

Predefined test parameters:

Domains of input array elements

-100 <= A[INDEX_0] <= 100

Domains of input variables

-100 <= x <= 100

8 <= dim(A) <= 8

Simple preconditions (inequalities)

Quantified preconditions

for all INDEX

such that:

INDEX < 7

we have: A[INDEX] <= A[INDEX+1]

Path selection strategy

all

C precondition was not found

Oracle function in C language

```
void oracle_Bsearch(
  int *Pre_A, int *A,
  int Pre_x, int x,
  int pathcrawler__retres__Bsearch)
{
  int i;
```

Oracle:

```
void oracle_Bsearch(
  int *Pre_A, int *A,
  int Pre_x, int x,
  int pathcrawler__retres__Bsearch)
{
  int i;
  int present = 0;
  int modif = 8;

  for(i=0; i<8; i++) {
    if(A[i] != Pre_A[i])
      modif = i;
    if(Pre_A[i] == Pre_x)
      present = 1;
  }
  if(present==0 && present != pathcrawler__retres__Bsearch) {
    pathcrawler_verdict_failure(); } /* line 17: implementation
wrongly found x in A */
  else {
    if(present==1 && present != pathcrawler__retres__Bsearch) {
      pathcrawler_verdict_failure(); } /* line 20: implementation
wrongly said x was not in A */
    else {
      if(modif < 8) {
     pathcrawler_verdict_failure(); } /* line 23: implementation
modified A */
      else {pathcrawler_verdict_success();
      }
    }
  }
  return;
}
```

Example Chance. Function under test: **Bsearch**

```
/* Should return 1 if x is an element of ordered array A */
int Bsearch( int A[10], int x) // tested function
{
  int low, high, mid, found ;

  low = 0 ;
  high = 9 ;
  found = 0 ;
  while( high > low )                    // line 09
    { mid = (low + high) / 2 ;

      if( x == A[mid] )                  // line 12
         found = 1;

      if( x > A[mid] )                   // line 15
        low = mid + 1 ;
      else
        high = mid - 1;
    }
  mid = (low + high) / 2 ;

  if( ( found != 1)  && ( x >= A[mid]) ) // line 22
    found = 1;

  return found ;
}
```

Predefined test parameters and oracle: see Example UC

Example 11. Function under test: `Bsearch`

```
/* Should return 1 if x is an element of ordered array A */
int Bsearch( int A[8], int x) // tested function
{
  int low, high, mid, found ;

  low = 1 ;
  high = 7 ;
  found = 0 ;
  while( high > low )                    // line 09
    { mid = (low + high) / 2 ;

      if( x == A[mid] )                  // line 12
         found = 1;

      if( x > A[mid] )                   // line 15
        low = mid + 1 ;
      else
        high = mid - 1;
    }
  mid = (low + high) / 2 ;

  if( ( found != 1)  && ( x == A[mid]) ) // line 22
    found = 1;

  return found ;
}
```

Predefined test parameters and oracle: see Example UC

Example 12. Function under test: `CompareBsearchSpec`

```
/* Should return 1 if x is an element of ordered array A */
int Bsearch( int A[8], int x)
{
  int low, high, mid, found ;

  low = 1 ;
  high = 7 ;
  found = 0 ;
  while( high > low )                    // line 09
    { mid = (low + high) / 2 ;

      if( x == A[mid] )                  // line 12
         found = 1;

      if( x > A[mid] )                   // line 15
        low = mid + 1 ;
      else
        high = mid - 1;
    }
  mid = (low + high) / 2 ;

  if( ( found != 1)  && ( x == A[mid]) ) // line 22
    found = 1;

  return found ;
}

int spec_Bsearch(
  int *Pre_A, int *A,
  int Pre_x, int x,
  int result_implementation)
{
  int i;
  int present = 0;
  int modif = 8;

  for(i=0; i<8; i++)                     // line 38
    {
      if(A[i] != Pre_A[i])               // line 40
        modif = i;
      if(Pre_A[i] == Pre_x)              // line 42
       present = 1;
    }
  if(present==0 && present != result_implementation) {
    return 0; } /* implementation wrongly found x in A */
  else {
    if(present==1 && present != result_implementation) {
      return 0; } /* implementation wrongly said x was not in A */
    else {
      if(modif < 8) {                    // line 51
       return 0; } /* implementation modified A */
      else return 1;
    }
  }
  return;
}

int CompareBsearchSpec(int A[8], int x) // tested function
{
  int *Pre_A = (int *)malloc(8 * sizeof(int));
  int i;
  for (i = 0; i < 8; i++)                // line 64
    Pre_A[i] = A[i];
  int result_implementation=Bsearch(A,x);
  return(spec_Bsearch(Pre_A,A,x,x,result_implementation));
}
```

Predefined test parameters: see Example UC

Oracle:

```
void oracle_CompareBsearchSpec(
  int *Pre_A, int *A,
  int Pre_x, int x,
  int pathcrawler__retres__CompareBsearchSpec)
{
  if (pathcrawler__retres__CompareBsearchSpec) {
    pathcrawler_verdict_success(); }
  else {
    pathcrawler_verdict_failure(); }
  return;
}
```

Example 13. Function under test: `f`

```
int x, y;
int f ( int a ) {
  int sum;
  if(a == 0){  // line 4
    x = 0; y = 0;
  }else{
    x = 5; y = 5;
  }
  sum = x + y; // sum can be 0
  pathcrawler_assert( sum != 0 );
  return 10 / sum; // risk of division by 0
}
```

Example 14. Function under test: `f`

```
int x, y;
int f ( int a ) {
  int sum;
  if(a == 0){  // line 4
    x = 0; y = 5;
  }else{
    x = 5; y = 0;
  }
  sum = x + y; // sum cannot be 0
  pathcrawler_assert( sum != 0 );
  return 10 / sum; // risk of division by 0
}
```

Example 15. Function under test: `ArrayCmp`

```
/* compares (with respect to the lexicographic order) the
subarrays
with the first n elements of given arrays t1 and t2,
returns  0 if the subarrays are equal,
         1 if the subarray in t1 is greater than in t2,
        -1 if the subarray in t2 is greater than in t1
*/

int ArrayCmp(int n, int* t1, int* t2) {
  int i;
  for (i = 0; i <= n; i++) {   /* line 10 */
    if (t1[i] > t2[i])         /* line 11 */
      return -1;
    else if (t1[i] < t2[i])    /* line 13 */
      return 1;
  }
  return 0;
}
```

Example 16. Function under test: `ArrayCmp`

```
/* compares (with respect to the lexicographic order) the subarrays
with the first n elements of given arrays t1 and t2,
returns  0 if the subarrays are equal,
         1 if the subarray in t1 is greater than in t2,
        -1 if the subarray in t2 is greater than in t1
*/

int ArrayCmp(int n, int* t1, int* t2) {
  int i;
  for (i = 0; i < n; i++) {   /* line 10 */
    if (t1[i] > t2[i])        /* line 11 */
      return -1;
    else if (t1[i] < t2[i])   /* line 13 */
      return 1;
  }
  return 0;
}
```

Oracle:

```
void oracle_ArrayCmp(
  int Pre_n, int n,
  int *Pre_t1, int *t1,
  int *Pre_t2, int *t2,
  int pathcrawler__retres__ArrayCmp)
{
  int i;
  for( i=0; i<pathcrawler_dimension(t1); i++ )
    if( t1[i] != Pre_t1[i] )
      { pathcrawler_verdict_failure(); return; } // line 10: t1 changed

  for( i=0; i<pathcrawler_dimension(t2); i++ )
    if( t2[i] != Pre_t2[i] )
      { pathcrawler_verdict_failure(); return; } // line 14: t2 changed

  for( i=0; i<n; i++ )
    if( t1[i] != t2[i] )
      break;

  if( i==n )                                    // the subarrays are equal
    if( pathcrawler__retres__ArrayCmp == 0 )
      { pathcrawler_verdict_success(); return; } // correctly reported
    else
      { pathcrawler_verdict_failure(); return; } // line 24: wrongly reported

  if( t1[i]>t2[i] )                             // the subarray in t1 greater
than in t2
    if( pathcrawler__retres__ArrayCmp == 1 )
      { pathcrawler_verdict_success(); return; } // correctly reported
    else
      { pathcrawler_verdict_failure(); return; } // line 30: wrongly reported
  else                                          // the subarray in t2 greater
than in t1
    if( pathcrawler__retres__ArrayCmp == -1 )
      { pathcrawler_verdict_success(); return; } // correctly reported
    else
      { pathcrawler_verdict_failure(); return; } // line 35: wrongly reported
}
```

Example 17. Function under test: `bsort`

```
/* Bubble sort of a given array 'table' of
   a given length 'l' in ascending order */

void bsort (int * table, int l)
{
  int i, temp, nb;
  char done;
  done = 0;
  nb = 0;
  while ( !done && (nb < l-1)){       /* line 10 */
    done = 1;
    for (i=0 ; i<l-1 ; i++)           /* line 12 */
      if (table[i] > table[i+1]){     /* line 13 */
     done = 0;
     temp = table[i];
     table[i + 1] = temp;
      }
    nb++;
  }
}
```

Oracle:

```
void oracle_bsort(
  int *Pre_table, int *table,
  int Pre_l, int l)
{
  int i, k;
  k = 0;
  for(i=0; i<l; i++)
    {
      if(i != l-1 && table[i] > table[i+1])
       {
         pathcrawler_verdict_failure(); /* line 36: Result array is not sorted */
         return;
       }
      while(Pre_table[k] != table[i])
          if(k == l-1)
           {
             pathcrawler_verdict_failure(); /* line 42: Element present only in result
array */
             return;
           }
          else
            k++;
      if(i != l-1)
        /* if the element is repeated, next time only look in the rest of Pre_table */
        if(table[i] == table[i+1])
          if(k == l-1)
           {
             pathcrawler_verdict_failure(); /* line 52: Element present only in result
array */
             return;
           }
          else
            k++;
        else
          k = 0;
    }
  pathcrawler_verdict_success();
  return;
}
```