Program Verification
Array Assignments

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Lecture 21

Based on work by J. Buss, L. Kari, A. Lubiw, B. Bonakdarpour, D. Maftuleac, C. Roberts, R. Trefler, and P. Van Beek

Outline

Learning Goals

By the end of this lecture, you should be able to:
Partial correctness for array assignments

- Prove that a Hoare triple is satisfied under partial correctness for a program containing array assignment statements.

The array assignment inference rule

Let A be an array of n integers.

Consider the following triple. What should the precondition be?

```
(| ??? |)
A[x] = 1;
(| A[y] = 0 |)          array assignment
```

- If $x = y$, the precondition should be ...?
- If $x \neq y$, the precondition should be ...?

We are using variables as indices into arrays. We must consider multiple cases for all possible values of the variables.

The array assignment inference rule

Let A be an array of n integers.

First, write down the sequence of changes.
Resolve all of the changes when we prove the implied's.

$(\!|\, Q[A\{e1 \leftarrow e2\}/A] \,|\!)$

```
A[e1] = e2;
```

$(\!|\, Q \,|\!)$ array assignment

- A is the original array.
- $A\{e1 \leftarrow e2\}$ is the new array, which is identical to array A except that the $e1^{th}$ element is $e2$.

The array re-assignment notation

The array reassignment notation:

$$A\{e1 \leftarrow e2\}[i] = \begin{cases} e2, & \text{if } i = e1 \\ A[i], & \text{if } i \neq e1 \end{cases}$$

Note that $e1$ is an index whereas $e2$ is an array element.

We apply assignments from left to right.

Examples:

- $A\{1 \leftarrow 3\}[1] = 3$
- $A\{1 \leftarrow 3\}\{1 \leftarrow 4\}[1] = 4$

CQ 1 Applying the array assignment rule

CQ 1: What is the precondition derived using the array assignment inference rule?

$\llparenthesis$??? $\rrparenthesis$
```
A[1] = 2;
```
$\llparenthesis\, A[x] = y0 \,\rrparenthesis$ `array assignment`

(A) $A\{1 \leftarrow 1\}[x] = y0$

(B) $A\{1 \leftarrow 2\}[x] = y0$

(C) $A\{2 \leftarrow 1\}[x] = y0$

(D) $A\{2 \leftarrow 2\}[x] = y0$

(E) None of the above

CQ 2 Applying the array assignment rule

CQ 2: What is the precondition derived using the array assignment inference rule?

$(\!|\, ??? \,|\!)$

```
A[1] = 2;
```

$(\!|\, A\{3 \leftarrow 4\}[x] = y0 \,|\!)$ `array assignment`

(A) $A\{1 \leftarrow 2\}\{3 \leftarrow 4\}[x] = y0$

(B) $A\{3 \leftarrow 4\}\{1 \leftarrow 2\}[x] = y0$

(C) None of the above

CQ 3 Applying the array assignment rule

CQ 3: What is the precondition derived using the array assignment inference rule?

$(\!|\ ???\ |\!)$

```
A[1] = 2;
```

$(\!|\ A\{3 \leftarrow A[y]\}[x] = y0\ |\!)$ array assignment

(A) $A\{1 \leftarrow 2\}\{3 \leftarrow A[y]\}[x] = y0$

(B) $A\{1 \leftarrow 2\}\{3 \leftarrow A\{1 \leftarrow 2\}[y]\}[x] = y0$

(C) None of the above

Example of the array assignment rule

Example:

Prove that the following triple is satisfied under partial correctness.

$(\!|\, ((A[x] = x0) \wedge (A[y] = y0)) \,|\!)$

```
t = A[x];

A[x] = A[y];

A[y] = t;
```

$(\!|\, ((A[x] = y0) \wedge (A[y] = x0)) \,|\!)$

Reversing an array

Consider an array R of n integers, $R[1], R[2], ..., R[n]$.

We want to reverse the order of its elements.

Our algorithm:

For each $1 \leq j \leq \lfloor n/2 \rfloor$,
we will swap $R[j]$ with $R[n+1-j]$.

Reversing an array

R is an array of n integers, $R[1], R[2], ..., R[n]$. Prove that the following triple is satisfied under partial correctness.

$$(\!| (\forall x \, ((1 \leq x \leq n) \rightarrow (R[x] = r_x))) |\!)$$

```
j = 1;
while (2 * j <= n) {
   t = R[j];
   R[j] = R[n+1-j];
   R[n+1-j] = t;
   j = j + 1;
}
```

$$(\!| (\forall x \, ((1 \leq x \leq n) \rightarrow (R[x] = r_{n+1-x}))) |\!)$$

Reversing an array

R is an array of n integers, $R[1], R[2], ..., R[n]$. Prove that the following triple is satisfied under partial correctness.

Let $Inv(j)$ denote our invariant.

$$(\!|\ (\forall x\ ((1 \leq x \leq n) \rightarrow (R[x] = r_x)))\ |\!)$$

```
j = 1;
while (2 * j <= n) {
  t = R[j];
  R[j] = R[n+1-j];
  R[n+1-j] = t;
  j = j + 1;
}
```

$$(\!|\ (\forall x\ ((1 \leq x \leq n) \rightarrow (R[x] = r_{n+1-x})))\ |\!)$$

Revisiting the learning goals

By the end of this lecture, you should be able to:
Partial correctness for array assignments

- Prove that a Hoare triple is satisfied under partial correctness for a program containing array assignment statements.