Modern programming languages have many different classes of Variables, e.g.

1. Global variables
2. Parameters
3. (function) local variables (also called automatic or activation-specific)
4. (object-oriented) member variables
5. Etc.

It is the job of the language system to keep track of the values of these variables during the runtime of a program.

⇒ The language system accomplishes this by binding a variable to a memory location and then uses that memory location to store the value of the variable.
Memory Locations for Variables

In imperative programs this is a fairly transparent process - the assignment operator mimics what happens at the hardware level - namely, the updating of memory cells.

In functional languages this is often not so obvious, since there is no global State, but still, variables are bound to memory locations.
In order to track variables for functions, compilers use a data structure called activation record - collects all the variables belonging to one function into this structure.

**Example: FORTRAN**

```fortran
FUNCTION AVG (M,N)
SUM = M + N
AVG = SUM/2.0
RETURN
END
```

Code:

```
(Main) ...
AVG(4,2) ...
AVG ...
RETURN
```

Global Data:

```
M
N
SUM
<return addr>
```

Activation Record
Note: Non-recursive languages such as FORTRAN keep a single activation record per function in the program.

Recursive languages (ML, Java, C, C++, etc) keep a stack of activation records; one per function call.
The Runtime Stack

Code:

(Main)
...

(function code)
...

RETURN

Global Data:

<Stack pointer>

Activation Record

<local vars>
<return addr>
<next record>

Activation Record

<local vars>
<return addr>
<next record>

Runtime Stack
We are evaluating `fact(3)`. This shows the contents of memory just before the recursive call that creates a second activation.
This shows the contents of memory just before the third activation.

```java
int fact(int n) {
    int result;
    if (n<2) result = 1;
    else result = n * fact(n-1);
    return result;
}
```
Java Example

This shows the contents of memory just before the third activation returns.

```java
int fact(int n) {
    int result;
    if (n<2) result = 1;
    else result = n * fact(n-1);
    return result;
}
```
The second activation is about to return.
The first activation is about to return with the result $\text{fact}(3) = 6$. 

```java
int fact(int n) {
    int result;
    if (n<2) result = 1;
    else result = n * fact(n-1);
    return result;
}
```
fun halve nil = (nil, nil)
| halve [a] = ([a], nil)
| halve (a::b::cs) = 
  let
    val (x, y) = halve cs
  in
    (a::x, b::y)
  end;

We are evaluating \textbf{halve [1,2,3,4]}. This shows the contents of memory just before the recursive call that creates a second activation.
fun halve nil = (nil, nil)
|   halve [a] = ([a], nil)
|   halve (a::b::cs) =
|   let
|     val (x, y) = halve cs
|   in
|     (a::x, b::y)
|     end;

This shows the contents of memory just before the third activation.
fun halve nil = (nil, nil)
|   halve [a] = ([a], nil)
|   halve (a::b::cs) =
|       let
|           val (x, y) = halve cs
|       in
|           (a::x, b::y)
|       end;

This shows the contents of memory just before the third activation returns.
fun halve nil = (nil, nil)
|   halve [a] = ([a], nil)
|   halve (a::b::cs) =
|       let
|       val (x, y) = halve cs
|       in
|       (a::x, b::y)
|       end;

The second activation is about to return.
fun halve nil = (nil, nil)
|   halve [a] = ([a], nil)
|   halve (a::b::cs) = 
  let
    val (x, y) = halve cs
  in
    (a::x, b::y)
  end;

The first activation is about to return with the result \( \text{halve } [1,2,3,4] = [1,3],[2,4] \)