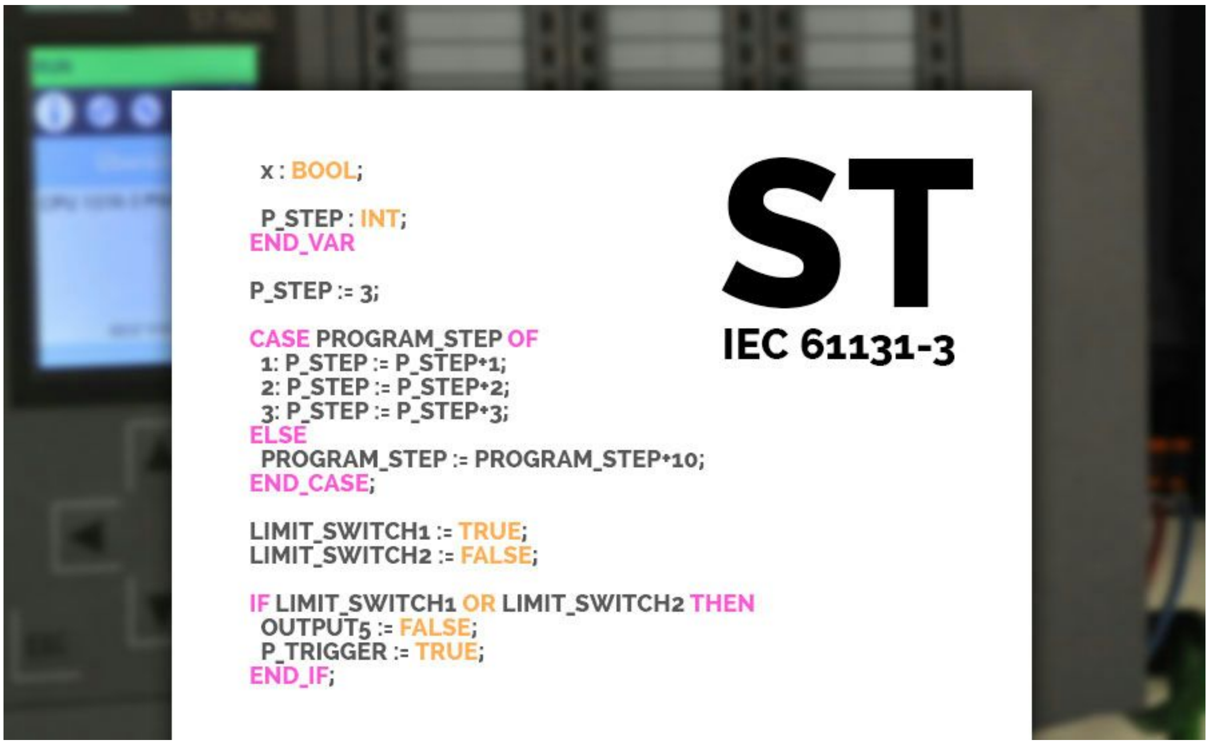
# Structured Text (ST)

*PLC Programming with IEC-61131-3*

*Peter* | *www.plcacademy.com*



```
  x : BOOL;

  P_STEP : INT;
END_VAR

P_STEP := 3;

CASE PROGRAM_STEP OF
  1: P_STEP := P_STEP+1;
  2: P_STEP := P_STEP+2;
  3: P_STEP := P_STEP+3;
ELSE
  PROGRAM_STEP := PROGRAM_STEP+10;
END_CASE;

LIMIT_SWITCH1 := TRUE;
LIMIT_SWITCH2 := FALSE;

IF LIMIT_SWITCH1 OR LIMIT_SWITCH2 THEN
  OUTPUT5 := FALSE;
  P_TRIGGER := TRUE;
END_IF;
```

## Content of Structured Text Tutorial

## What is Structured Text Programming?

Structured Text is PLC programming language defined by **PLCOpen** in **IEC 61131-3**. The programming language is text-based, compared to the graphics-based ladder diagram.
At first, it may seem better to use a graphical programming language for PLC programming. But in my opinion, that is only true for smaller PLC programs. By using a text-based PLC programming language, your program will take up much smaller space, and the flow/logic will be easier to read and understand.

Another advantage is that you can combine the different programming languages. You can even have function blocks containing functions written in Structured Text.

### High-level Programming Languages

If you are already familiar with high-level programming languages like PHP, Python and C, Structured Text will seem familiar to you. The syntax of Structured Text is developed to look like the syntax of a high-level programming language with loops, variables, conditions and operators.

But on the other hand, if you have never seen a high-level programming language, Structured Text can be a great introduction to those languages and the syntax used. Before you read this tutorial I recommend that you take a brief look at this PLC program written in Structured Text. Try to see if you can understand the function of this program. Does Structured Text look familiar to you?

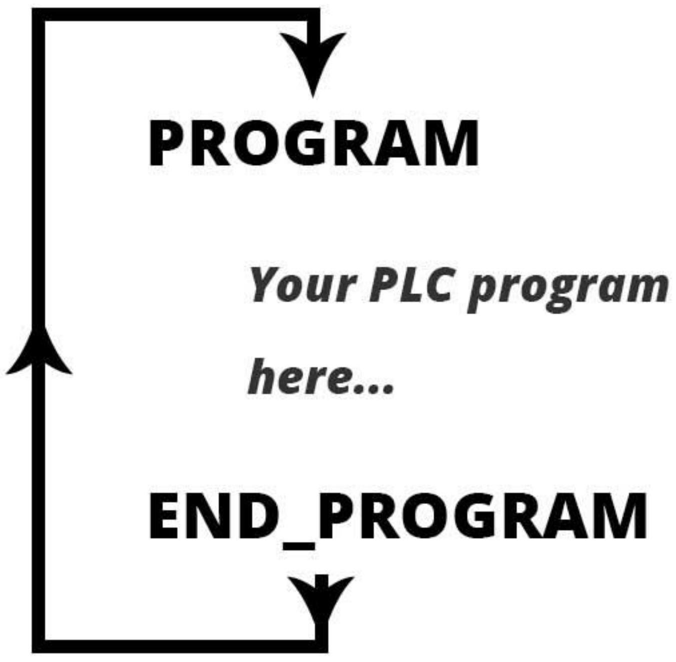
```
PROGRAM stexample
  VAR
    x : BOOL;
  END_VAR
  x := TRUE;
  REPEAT
    x := FALSE;
  UNTIL x := FALSE;
  END_REPEAT;
END_PROGRAM;
```

## The Flow of Structured Text

The first thing you should learn is the structure or the syntax of Structured Text. When you understand the structure, you will understand how the flow of your program works.

Starting with the example above, you can see that the whole program begins with **PROGRAM** and ends with **END_PROGRAM**. Everything in between is your PLC program. These two words are the delimiting keywords for program declarations. More on keywords later.

Don't be confused about the END_PROGRAM, because your program won't end completely here. When the PLC reaches the END_PROGRAM the PLC scan cycle will start over again, and your program will repeat itself.



*Structured Text Program Flow.*

This is just like ladder logic or any other PLC programming language - it will run over and over again. And if you are used to programming microcontrollers, the PROGRAM/END_PROGRAM will be similar to the infinite loop in C.

One thing to add here is that, when you are programming in Structured Text, you will often not use the PROGRAM/END_PROGRAM construct. It will already be done by the PLC programming software, and the code you have to write, is what you want inside that construct.

The flow control of PLC programs written in Structured Text is the same as in ladder logic: *execute one line at a time*.

## Starting with the Syntax of Structured Text

The syntax of a programming language is the definition of how it is written. To be more precise, what symbols is used to give the language its form and meaning.

As you can see in the example, Structured Text is full of colons, semicolons and other symbols. All these symbols has a meaning and is used to represent something. Some of them are operators, some are functions, statements or variables.

All the details of the syntax will be explained as you move through this tutorial. But there are some general rules for the syntax of Structured Text you should know about.
You don't have to memorize all the syntax rules for now, as you will when you get your hands into the programming:

- All statements are divided by semicolons.
- Structured Text consists of statements and semicolons to separate them.
- The language is not case-sensitive.
- Even though it is good practice to use upper- and lowercase for readability, it's not necessary.
- Spaces have no function.
- But they should be used for readability.

What's really important to understand here is that, when you write a PLC program in Structured Text, your computer will translate that to a language the PLC can understand.

When you upload the Structured Text PLC program to your PLC, the programming software you use will **compile** your program. This means that it will translate the code to a sort of **machine code** which can be executed by the PLC.

The compiler uses the syntax of the programming language to understand your program.
For example: Each time the compiler sees a **semicolon**, it will know that the **end of the current statement** is reached. The compiler will read everything until it reaches a semicolon, and then execute that statement.

### Comment Syntax

In textual programming languages you have the ability to write text that doesn't get executed. This feature is used to make comments in your code.
Comments are good, and as a beginner you should always comment your code. It makes it easier to understand your code later.

In Structured Text you can make either one line comments or multiple line comments.

**Single line comment:**

*// comment*

**Comment after end of ST line:**
*<expression>; /* comment */*
or
*<statement>; (* comment *)*

**Multiple line comment:**
*/* start comment*
*…*
*end comment */*
or
*(* start comment*
*…*
*end comment *)*

## Should You Comment Every Detail?

As you gradually get better and better, you should make fewer and fewer comments about the functionality. The reason for this is The Tao of Programming, which is a book about programming inspired by the old Chinese Tao Te Ching. Or actually the principle behind the book is the reason.

Take this little story in chapter 2.4:
*A novice asked the Master: "Here is a programmer that never designs, documents or tests his programs. Yet all who know him consider him one of the best programmers in the world. Why is this?"*
*The Master replied: "That programmer has mastered the Tao. He has gone beyond the need for design; he does not become angry when the system crashes, but accepts the universe without concern. He has gone beyond the need for documentation; he no longer cares if anyone else sees his code. He has gone beyond the need for testing; each of his programs are perfect within themselves, serene and elegant, their purpose self-evident. Truly, he has entered the mystery of Tao."*

Although this might be put on the edge, you should always write your code so it is as easy as possible to understand. Even without comments. You start doing this by simply making the code easy to read with spaces.

But for now, you should not worry about comments. Make as many as you want while you are still a beginner.

## Making Statements with Structured Text

So, Structured Text consists of **statements**. But what is statements?
You probably know statements as something coming from humans. You can make a statement, a president or even a company can make a statement. And in PLC programming, statements are almost the same.

A **statement** is you telling the PLC what to do.

Let's take the first statement as an example:

*X : BOOL;*

The compiler will read this as **one statement**, because when it reaches the semicolon, it knows that this is the end of that statement.Remember, statements are separated by semicolons. That's the main syntax rule of this language.

In *this* statement you are telling the PLC to **create a variable** called **X** and that variable should be a **BOOL** type.

## Using Variables in Structured Text

Before we dig deeper into the statement, let me get back to the keywords i mentioned before. As you can see, the variable X is defined in between two other keywords - **VAR** and **END_VAR**.

Both the PROGRAM/END_PROGRAM and VAR/END_VAR are **constructs**, meaning that they delimit a certain area in your program for something specific. The PROGRAM construct is where all your PLC program is, and the VAR construct is where you define variables.

All the four are called keywords, because they are reserved words. You can't use those words for anything else when you are programming in Structured Text. The name of your program cannot be PROGRAM or even program (STL is not case sensitive), because that word can only be used to make a construct to delimit your PLC program.

Back to **variables**...

If you know other programming languages, chances are that you know about variables already.
But if you don't, here's an introduction to variables you probably will like:

*A variable is a place where you can store data.*

Depending on what type of data you want to store, there are several **data types** available. The different kinds of data are called data types. For example, if you have a variable where you want to store either **TRUE** or **FALSE**, you can declare it as a **BOOL** type.
The BOOL type is a **boolean data type** which means that it can contain a **boolean value** (TRUE or FALSE).

Now, that was two thing about variables. They have a certain data type, and they contain a value of that data type. But there's one more thing you can control in your variables. The name of the variable.

To make it easy for you to use your variables throughout your PLC program, they all have names. When you define a variable in the VAR construct, you start by giving the variable its name:

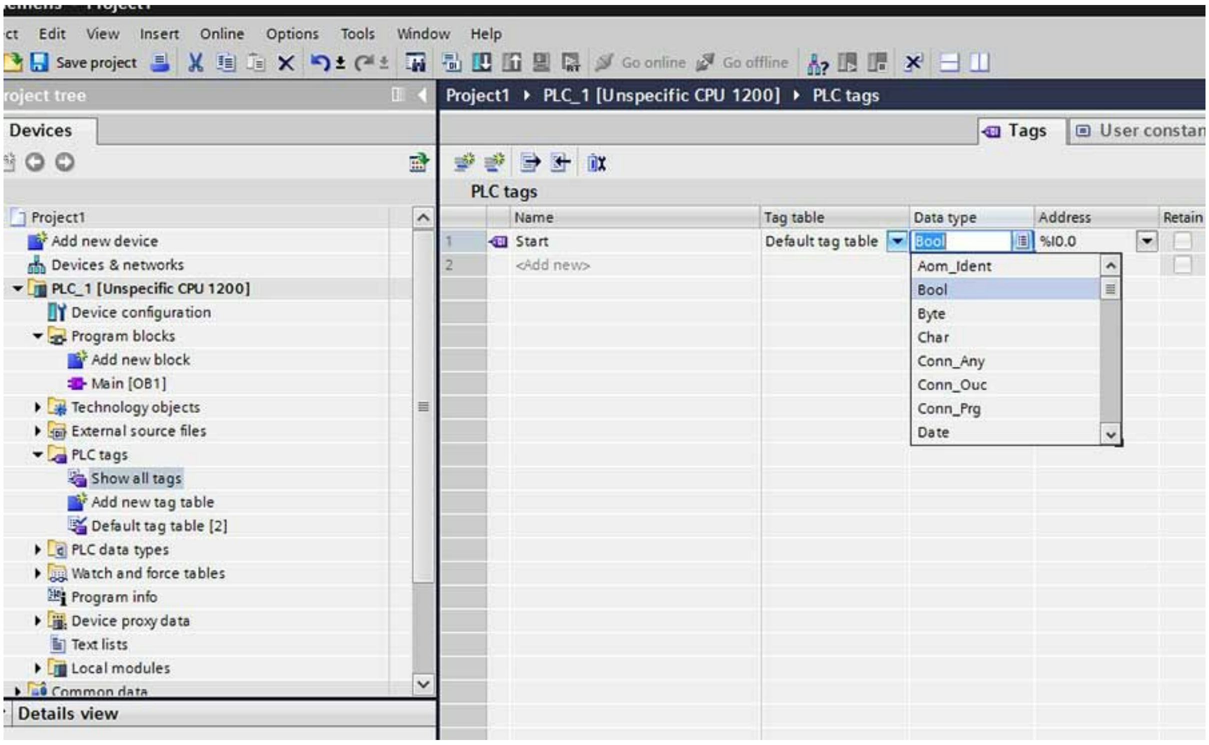
```
X : BOOL;
```

This statement will create a variable called X, with a BOOL data type.

Be aware, that when you are programming with some PLC software like Siemens STEP 7 or Rockwell you won't use the VAR/END_VAR til declare variables. Instead variables are often called tags or symbols, and even though you are programming in Structured Text, you declare them visually (like in the image below) or in a function block.

## Variables, Tags or Symbols?

One last thing to add here is that variables are often called **tags** in PLC programming. In the PLC programming software Studio 5000 Logix Designer for Allen Bradley PLC's, variables are called tags. But if you are programming in older versions of SIMATIC STEP 7 Programming Software for Siemens PLC's, variables are called symbols. In the newer versions of STEP 7 (from TIA Portal version 11) variables are called tags.



| | Name | Tag table | Data type | Address | Retain |
|---|---|---|---|---|---|
| 1 | Start | Default tag table | Bool | %I0.0 | |
| 2 | <Add new> | | | | |

*SIMATIC STEP 7 TIA Portal Variables called PLC tags.*

But no matter what variables are called, they always have the same function. And with IEC 61131-3 Programming software like STEP 7, Codesys or Studio 5000, the standard data types will always be available.

## Data Types in Structured Text

Depending on what PLC brand you are using, you will have some different data types available. In a Siemens PLC you have data types in STEP 7 available that are similar to the standard ones in IEC 61131-3. But you will also have other data types only used in SIEMENS PLC's like the S5TIME.

All the standard data types are defined by the PLCOpen Organization and they are part of the PLC programming languages. Every PLC programming software with Structured Text has these data types included. In the IEC standard the data types are divided into two categories: **Elementary data types** and **derived data types**.

**Elementary data types**

- Integers
- Floating points
- Time
- Strings
- Bit strings

Under each elementary data types there are several **IEC data types** available. These are the data types defined in **IEC 61131-3**:

**Integers:**

| **IEC Data Type** | **Format** | **Range** |
|---|---|---|
| SINT | Short Integer | -128 … 127 |
| INT | Integer | -32768 … 32767 |
| DINT | Double Integer | -2^31 … 2^31-1 |
| LINT | Long Integer | -2^63 … 2^63-1 |
| USINT | Unsigned Short Integer | 0 … 255 |
| UINT | Unsigned Integer | 0 … 2^16-1 |
| LDINT | Long Double Integer | 0 … 2^32-1 |
| ULINT | Unsigned Long Integer | 0 … 2^64-1 |

**Floating points:**

| **IEC Data Type** | **Format** | **Range** |
|---|---|---|
| REAL | Real Numbers | ±10^±38 |
| LREAL | Long Real Numbers | ±10^±308 |

**Time:**

| **IEC Data Type** | **Format** | **Use** |
|---|---|---|

| | | |
|---|---|---|
| TIME | Duration of time after an event | T#10d4h38m57s12ms<br>TIME#10d4h38m |
| DATE | Calendar date | D#1989-05-22<br>DATE#1989-05-22 |
| TIME_OF_DAY | Time of day | TOD#14:32:07<br>TIME_OF_DAY#14:32:07.77 |
| DATE_AND_TIME | Date and time of day | DT#1989-06-15-13:56:14.77<br>DATE_AND_TIME#1989-06-15-13:56:14.77 |

**Strings:**

| IEC Data Type | Format | Range |
|---|---|---|
| STRING | Character String | 'My string' |

**Bit strings:**

| IEC Data Type | Format | Range |
|---|---|---|
| BOOL | Boolean | 1 bit |
| BYTE | Byte | 8 bits |
| WORD | Word | 16 bits |
| DWORD | Double Word | 32 bits |
| LWORD | Long Word | 64 bits |

**Derived data types**

- Structured data types
- Enumerated data types
- Sub-ranges data types
- Array data types

The derived data types are your own **custom data types**. All the derived data types are built by making a construction of the keywords **TYPE** and **END_TYPE**. In between the keywords is the kind of derived data type you want to declare.

All these different data types might seem a little overwhelming for now. Especially if you haven't used a textual programming language before. But there's no need to worry.
For now, you only have to remember a few of them to get started programming with Structured Text. As you get better and your programs more complicated, you will gradually learn about more data types as you use them. What's important here is that you don't move ahead too fast. You want to get the basics right.

As you can see the different data types can hold different data formats and thereby different values.

But how do you put the values in the variables? And how do you use the variables? With statements and operators.

## Operators and Expressions in STL

The next thing you should know about is **operators**. Operators are used to **manipulate data** and is a part of almost any programming language. This leads us to the second thing you should know about - **expressions**.

Just like operators, expressions are a crucial part of programming languages.
*An **expression** is a **construct** that, when evaluated, **yields a value**.*

This means that when the compiler compiles an expression, it will evaluate the expression and replace the statement with the result.

Take this example with the two variables **A** and **B**.
**A** contains the value **10** and **B** contains **8**.

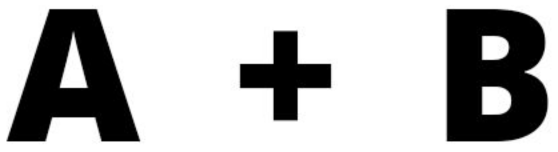
*A+B*

The result of this expression is **18**. So instead of A+B, the compiler will put in the value 18.

*An **expression** are composed of **operators** and **operands**.*

So what are operators and operands?

Since, you just saw an example of an expression, you just saw both an operator and two operands. A and B are both operands and the + is an operator.



*Programming language expressions with operands and operators.*

Remember that operators are used to manipulate data. That is exactly what the + is doing. It is taking the value of the variable A and adding it to the value in B.
The + is also called the addition operator because the operation is addition.

## Operators

There are several operators available in Structured Text. Again, IEC 61131-3 describes all the standard operators in the Structured Text language:

| Operation | Symbol | Precedence |
|---|---|---|
| Parenthesization | (expression) | Highest |
| Function Evaluation | MAX(A,B) | |
| Negation<br>Complement | -<br>NOT | |
| Exponentiation | ** | |
| Multiply<br>Divide<br>Modulo | *<br>/<br>MOD | |
| Add<br>Subtract | +<br>- | |
| Comparison | <, >, <=, >= | |
| Equality<br>Inequality | =<br><> | |
| Boolean AND<br>Boolean AND | &<br>AND | |
| Boolean Exclusive OR | XOR | |
| Boolean OR | OR | Lowest |

All the operators in the table above are sorted after **precedence**. This is also called order of operations, and you may know about if from mathematics.

The order of operations is the order in which the operations are executed or calculated. Just take a look at this expression:

*A + B * MAX(C, D)*

How will this expression be evaluated by the compiler?

As you can see in the table of operators the operator with the highest precedence is parenthesis. This means that the first thing, that will be evaluated, is everything in parenthesizes - in this example: (C, D).

But since MAX(C, D) is actually a function, we can jump one row down in the table to function evaluation.

So, in the above expression, the first thing that will be evaluated is the function: MAX(C, D). The function will yield (replace the function) with the answer. Which in this case is the highest of the two variables C and D.

Let's image C is the result. The expression will now look like this:

*A + B * C*

Now, you can go down through the table, until you reach a row with the next operator used in this expression.
There are two operations left: multiply and addition. But since multiply has a higher precedence, that will be the first to be evaluated.
B * C comes first and then the result is added to A.
Every time an expression is evaluated, the evaluation follows the order of precedence as in the table above.

## 4 Types of Operators, 4 Types of Expressions

The operators used for expressions in Structured Text can be divided into four groups. Each group of operators will have its specific function and will yield a specific data type.

1. **Arithmetic Operators**
2. **Relational Operators**
3. **Logical Operators**
4. **Bitwise Operators**

### Arithmetic Operators

All the **arithmetic operators** are often just called mathematical operators because they represent math. The result will always be the mathematical result of the expression.

- **+** (add)

- **-** (subtract/negate)
- ***** (multiply)
- ****** (exponent)
- **/** (divide)
- **MOD** (modulo divide)

**Example:**
*15 MOD 4*
**Result:**
*3*

### Relational Operators

To compare or find a relation between two values you can use one of the **relational operators**. They are used for comparison and the result will be a boolean value (BOOL type), either TRUE or FALSE.

- **=** (equal)
- **<** (less than)
- **<=** (less than or equal)
- **>** (greater than)
- **>=** (greater than or equal)
- **<>** (not equal)

**Example:**
*TEMPERATURE := 93.9;*
*TEMPERATURE >= 100.0*

**Result:**
*FALSE*

### Logical Operators

If you want to compare boolean values (BOOL) and make some logic out of it, you have to use **logical operators**. These operators also yields a boolean value of TRUE or FALSE as a result of the expression.

- **&** or **AND**
- **OR**
- **XOR**
- **NOT**

**Example:**
*LIMIT_SWITCH1 := TRUE;*
*LIMIT_SWITCH2 := FALSE;*
*LIMIT_SWITCH1 OR LIMIT_SWITCH2*

**Result:**
*TRUE*

**Bitwise Operators**
The last group of operators are called **bitwise operators** because the operations are performed bitwise. It simply means that a logic operation is performed for each bit of two numbers. The result is a new number - the total result of the bitwise operations.

- **&** or **AND**
- **OR**
- **XOR**
- **NOT**

**Example:**
*15 AND 8*

**Result:**
*15*

Since this operation is bitwise the calculation will be per bit. So to understand what's going on here, you have to convert the numbers to binary values:

15 = 1111
8 = 1000

Now each bit in the number 1111 (15) can be used in a logical operation with the other number 1000 (8):

*1111 AND 1000*

| **Bit number** | **1111 (15)** | **1000 (8)** | **Result** |
|---|---|---|---|
| 0 | 1 | 1 | **1** |
| 1 | 1 | 0 | **0** |
| 2 | 1 | 0 | **0** |
| 3 | 1 | 0 | **0** |

## Operators and Statements

So, in the previous section you learned that **expressions evaluate**. Meaning that all expressions will yield the result and the compiler will replace the expression with the result.
But what if you want the PLC (compiler) not to evaluate something, but to **DO** something?
**Statements** are the answer.

As I mentioned previously in this article, statements are you telling the PLC what to do. It's the instruction you give the PLC to take action.
If you make an expression that yields a result, that won't do much. Expressions are all the calculations and if you don't use the results of those expressions in some actions (statements), it will be like buying groceries but not cooking.

Let's take a look at the actions or statements that you can make in Structured Text.

### Assignment Statement and Operator

There are several statements available in Structured Text. All of them represent an **action** or a **condition**.

Beginning with actions, the most fundamental statement in Structured Text is the **assignment** statement. Statements are also described in the IEC standard developed by PLCOpen, and the first one they list is the assignment statement.

Here's how an assignment statement looks like:

*A := B;*

What does this statement tell the compiler to do?

To take the **value** of the variable **B** and put it in the variable **A**.

The PLC is **assigning** a value to a variable. Here's an even simpler example:

*A := 10;*

This statement will take the value 10 and put it into the variable A. Or said in another way - the variable A will be assigned the value 10.

Since the value of A is now 10, we can make another statement, but this time with an expression:

*B := A + 2;*

When this line of code is compiled, the expression A + 2 will be evaluated to 12. The compiler will replace the expression with the result 12. The statement will now look like this to the compiler:

```
B := 12;
```

What will happen now, is that the compiler will assign the value 12 to the variable B.

A := 8 + 2 ;

*How an assignment statement with an expression will be evaluated by the compiler.*

The last thing is that the := symbol is called the **assignment operator**. Yes, it is an operator just like the operators used in expressions. Often those two types of operators are mistaken for each other and used wrong.

A common mistake is to use the equality operator (=) instead of the assignment operator (:=). But even though they look like each other there's a huge difference.

Take these two examples:

```
A = B
A := B;
```

The first line is an expression. Since this is an expression, the operator will be used to evaluate the line. The equality operator evaluates in the following way:
If the right side and the left side is equal it evaluates to TRUE or 1. If not, it will evaluate to FALSE or 0.

With some other operators, the equality operator is a **relational operator**. All the relational operators will evaluate to either TRUE or FALSE.

On the second line you'll see a statement. This time the operator will be used for an action instead of an evaluation. Assignment is the action, and here the value of A will be given the value of B.

At last, you can always identify a statement by the semi colon. Once again, the semicolon is how the compiler knows when the end of a statement is reached.
You can have all sorts of expressions in your assignment statements, from simple values like numbers to variables and functions. Because all expressions will be evaluated first, and then, the result of that evaluation will be used in the assignment statement.

# Conditional Statements

Well, the assignment statement was pretty simple: Take the value of the right side and store it in what's on the left side.

But let's zoom out a bit and think about PLC programs. A PLC program is a piece of logic (I call it PLC logic) and therefore has to make some decisions. That's why we use a PLC or any other controller. To decide and act on the current state.
Simplified: The PLC will look at the states of all the inputs and use your PLC program to decide what outputs to set.

So in your PLC program you need a way to make decisions. This brings us to conditional statements.

Conditional statements are used for exactly that: ***To make decisions.***
There are two ways of doing conditional statements in Structured Text: **IF statements** and **CASE statements**.

## IF Statements

I think Bill Gates is better at explaining the IF statement than I am. At least he can explain it in just over 1 minute in this great video from code.org. You can skip the video if you are familiar with IF statements, although I would recommend that you watch it.

**YOUTUBE**

IF statements are decisions with conditions.

But even though IF-statements are quite simple to understand, you still have to know how to give the PLC the conditional statements. This brings us back to the syntax. There's a special syntax for IF statements. This means, that you have to write it in a certain way for the compiler to understand it. Because just like semi colons are used to end statements, there are special keywords to make an IF statement.

Here's how the syntax for IF statements looks like in STL:

```
IF [boolean expression] THEN
 <statement>;
ELSIF [boolean expression] THEN
 <statement>;
ELSE
 <statement>;
END_IF;
```

Notice that the syntax for IF statements looks very similar to plain English. The first line contains two keywords: IF and THEN. Between those two keywords are the condition, which is an expression. But not just any expression. A boolean expression.

**Boolean and Numeric Expressions**

You can divide expressions into two groups depending on what they yield.
Boolean expressions evaluates to a BOOL type value, TRUE or FALSE.

Here's an example of a boolean expression:

*1 = 1*

This expression will evaluate to or yield TRUE. A boolean expression could also look like this:

*1 > 2*

But this time the boolean expression will evaluate to FALSE, since 1 is not larger than 2.
Numeric expressions evaluates to an integer or a floating point number.

A numeric expression could look as simple as this one:

*13.2 + 19.8*

This expression will evaluate to the floating point number 33.0, and therefore is a numeric expression.

Boolean expressions are used in IF statements as conditions.
***IF** the boolean expression evaluates to TRUE, **THEN** the following statements will be executed.*

The PLC will only execute the statements after the keyword THEN, if the expression evaluates to TRUE. This is illustrated by the following example:

```
A := 0;
IF A = 0 THEN
 B := 0;
END_IF;
```

Line number 3 will only be executed if A is equal to 0. In this case it will. A 0 is assigned to the variable A in a statement right before the IF statement.

See what I just did here?

In the example above a decision was made depending on the value of a variable. Now, even though this was a fairly simple decision, we can already translate that into real PLC programming.

Let's say you want to make a program that sets a PLC output depending on the state of an input. With a simple IF statement you can do that in Structured Text:

```
IF INPUT1=TRUE THEN
 OUTPUT1 := TRUE;
END_IF;
```

Although this example is just a piece of a bigger program (the variable INPUT1 represents an input and OUTPUT1 an output) it illustrates how the decision for a PLC output can be made. The OUTPUT1 variable will only be set to TRUE IF the INPUT1 variable is TRUE.

Since, both the INPUT1 and OUTPUT1 variables are of the type BOOL, the first line in the statement could also look like this:

```
IF INPUT1 THEN
```

Just writing the expression as "INPUT1" will still evaluate as TRUE, when the variable is TRUE.

## What ELSE IF not?

For now, you've seen a simple IF statement, where statements are only executed if an expression is TRUE. If that expression evaluates to FALSE the statements will simply not be executed.

But what if your PLC program requires multiple conditions?

Of course you could write this as multiple individual IF statements. But Structured Text has more options to the IF statements.
Just like most other programming languages you can use the **ELSIF** and **ELSE** keywords for multiple conditions in the same IF statement.

Both ELSIF and ELSE are optional in IF statements, but this is how the syntax looks like:

```
IF [boolean expression] THEN
 <statement>;
ELSIF [boolean expression] THEN
 <statement>;
ELSE
```

```
 <statement>;
END_IF;
```

If the boolean expression on line 1 is FALSE, the statements below will simply not be executed. Instead the compiler will check the boolean expression after the ELSIF keyword.
Here it works just like with the IF keyword: If the boolean expression after the keyword is true, the following statements will be executed.

At last is the **ELSE** keyword. It works as a default option for your IF statement. If all the IF and ELSIF boolean expressions are evaluated to FALSE, the statements after the ELSE keyword will be executed.

IF A = 1
ELSIF A = 2
ELSE

*How the PLC will execute IF statements in Structured Text.*

## Combining Operators for Advanced Conditions

Beside making multiple conditions you can also expand your conditions to include multiple variables.  You can combine multiple expressions, typically done with a logical operator, to get a larger expression.
What if you want not just 1 but 2 inputs to be TRUE before an output is set. The expression would look like this:

```
IF (INPUT1) AND (INPUT2) THEN
  OUTPUT1 := TRUE;
END_IF;
```

Now the expression will evaluate to TRUE, only if INPUT1 and INPUT2 is TRUE.

## CASE Statements

The second way of making decisions in Structured Text is with CASE statements. Essentially, CASE statements and IF statements are the same. But CASE statements use **numeric expressions** instead of boolean expressions. CASE statements also have a slightly different syntax, that makes it more suitable for certain purposes.

This is how the syntax for CASE statements looks like in Structured Text:

```
CASE [numeric expression] OF
  result1: <statement>;
  resultN: <statemtent>;
ELSE
  <statement>;
END_CASE;
```

In CASE statements there are only 1 expression. The result of that expression is then used to decide which statements that are executed.

As a default option, CASE statements also have an ELSE keyword. The statements after that keyword are executed only if none of the results (or cases) matches the result of the numeric expression.
Here's a very simple example:

```
PROGRAM_STEP := 3;
CASE PROGRAM_STEP OF
  1: PROGRAM_STEP := PROGRAM_STEP+1;
  2: PROGRAM_STEP := PROGRAM_STEP+2;
  3: PROGRAM_STEP := PROGRAM_STEP+3;
ELSE
  PROGRAM_STEP := PROGRAM_STEP+10;
END_CASE;
```

Although this is a very simple example (the variable has a fixed value) the example shows you how to make a decision depending on the result of a numeric expression. In this example the numeric expression is simply just the value of the variable, 3. If could be any expression that evaluates to an integer or a floating point value.

# Iteration with Repeating Loops

Probably one of the most powerful features in Structured Text is the ability to make loops that repeat lines of code.

Once again, Code.org has made one of the best introductions to repeating loops. This time, Facebook founder, Mark Zuckerberg uses a little more than a minute to explain repeating loops.

**YOUTUBE**

In relation to PLC programming loops can be used for many different purposes. You might have a function or a set of statements that you want to execute a certain amount of times or until something stops the loop.

In Structured Text you will find 3 different types of repeating loops:

1. **FOR**
2. **WHILE**
3. **REPEAT**

Common for all the types of loops is that they have a condition for either repeating or stopping the loop. The condition in **FOR** and **WHILE loops** decides whether the loop should **repeat or not**. But for the **REPEAT loop** the condition is an **UNTIL condition**, and it will decide whether the loop should **stop or not**.

## FOR Loops

The first loop is the FOR loop and is used to repeat a specific number of times. FOR loops has some other keywords. TO, BY, DO and END_FOR.

This is the syntax of FOR loops in Structured Text:

```
FOR count := initial_value TO final_value BY increment DO
 <statement>;
END_FOR;
```

At first sight the first line looks a bit complicated, but it isn't if you divide it in chunks:

*FOR*
Keyword that starts the FOR loop statement.

*count := initial_value*
This assignment operation is where you set the initial value you want to count from. Count is the variable name and initial_value is the value you want to start counting from.

*TO*

Keyword before the value to count up to.

*final_value*
This is the value you want to count to. Place 100 here and your loop will count up to 100.

*BY*
Keyword to use custom incremental value.

*increment*
The value of which you want to increase the count for every time the loop runs. If you set the increment to 10 and the count to 100, the loop will run 10 times.

```
DO
<statement>;
END_FOR;
```

This last part between the keyword DO and END_FOR is the statements you want to execute each time your loop runs. These statements will be executed as many times as the loops repeats.

Since FOR loops can only have a preset amount of time they will repeat, that is what they are used for. In PLC programming this could be something as simple as an item that has to be painted/dried four times. A FOR loop that counts to four will work just fine here.

At last you can use an IF statement with the keyword **EXIT** to stop the loop before the count. You can add a boolean condition that if TRUE stops the loop.

```
IF [boolean expression] THEN
  EXIT;
END_IF;
```

## WHILE Loops

The while loop is a little different from the FOR loop, because it is used to repeat the loop as long as some conditions are TRUE. A WHILE loop will repeat as long as a boolean expression evaluates to TRUE.

Here's the syntax of WHILE loops:

```
WHILE [boolean expression] DO
  <statement>;
END_WHILE;
```

Between the WHILE and DO keywords are the boolean expression. If that boolean expression evaluates to TRUE, all the statements until the END_WHILE keyword will be executed.

When END_WHILE is reached, the boolean expression will be evaluated again. This will happen over and over again until the expression doesn't evaluate to TRUE. But to make the loop stop at one point, you have to change a value in the boolean expression. Only in that way can the boolean expression go from TRUE to FALSE.

Here's an example of a WHILE loop in Structured Text:

```
counter := 0;
WHILE counter < 10 DO
  counter := counter + 1;
  machine_status := counter * 10;
END_WHILE;
```

If you look at the third line you will see how the loop will eventually stop repeating. The boolean expression uses the counter variable and checks if its value is less than or equal to 10. But since the value of counter is set to 0 right before the WHILE loop, the boolean expression will be TRUE unless counter is changed.

That is what's happening in line 3. This is the first statement in the WHILE loop, and with the other statements, are executed each time the loop repeats. In the third line the value of the counter variable is increased by 1. You can say that the incremental value is 1.
In the example above, the loop will repeat 10 times. When the value of count reaches 10, the boolean expression will be evaluated to FALSE (because 10 is not less than 10) and the loop will stop.

You can also use the EXIT keyword in the WHILE loop to stop repeating the loop before the boolean expression is FALSE. The syntax is an IF statement with the EXIT keyword in. Place it anywhere between DO and END_WHILE keywords.

```
IF [boolean expression] THEN
  EXIT;
END_IF;
```

## REPEAT Loops

The last type of repeating loop in Structured Text is the REPEAT loop. It works the opposite way of the WHILE loop. This loop will stop repeating when a boolean expression is TRUE.

In ST, the syntax for REPEAT loops looks like this:

```
REPEAT
  <statement>;
UNTIL [boolean expression]
END_REPEAT;
```

Notice here that since the boolean expression in this type of loop is after the statements, the statements will always be executed at least one time. This is useful if you want an action to happen one time and then, with a condition, decide if that action should happen again.

Just as with the WHILE loops you have to change a value in the boolean expression along the way, to make the loop stop repeating. This can be done by incrementing the value of a variable (to count), or it can be done with a conditional statement like an IF statement inside the loop.

## Structured Text Programming Software

Now, even if you have read this article in detail, you've only started learning Structured Text. What you should do now is get your hands in the dirt and start using Structured Text.

You should write some PLC programs. Because that is the way to really learn Structured Text and master the programming language.

### Beckhoff TwinCat 3

One of the best pieces of PLC programming software when you want to learn Structured Text is Beckhoff TwinCat 3. The programming software from Beckhoff is fully compatible with all the IEC 61131-3 PLC programming languages including Ladder Diagram (LD) and Structured Text (ST).

For learners, the biggest advantage of TwinCat 3 is that it has a simulator included. You don't need to buy a PLC, you just use the **soft PLC**.

On YouTube there is a free series of videos from SquishyBrained. You should follow him! He even made a video series about his DIY 3D Printer. It's a great video tutorial to get you started with Structured Text PLC programming in TwinCat 3.

**YOUTUBE**

### Codesys

You may have heard of Codesys before. It is an open source software environment for IEC 61131-3 PLC programming. Open source just means that it is free for download, which makes it perfect for students.

Although there are not many great resources on how to use Codesys for beginners, Brian Hobby has made some amazing tutorial videos.

The first video shows you how to create a new project in Codesys. A little Ladder Logic is also included in the video.

**YOUTUBE**

The second video helps you program in Structured Text with Codesys.

**YOUTUBE**

## Conclusion

Learning a new programming language can be quite a challenge. But for beginners there are some very basic things you should always keep in mind:

- **Learning takes time**
- You just started out. Give yourself some time to learn the language (syntax, functions, ...)
- **Practice as much as possible**
- Try to make as many PLC programs and solutions in Structured Text as possible.
- **Learn from your failures**
- Every time you make a mistake, don't get sad. Learn from it, and become a better programmer.
- **Keep learning**
- Never stop reading, watching tutorials and other learning materials.
- **Talk to other PLC programmers**
- The last but not least is discussing in forums and asking questions. Get involved and learn from other PLC programmers.

I think, that the last part is the most important part. Learning from others with experience can be the most effective way to learn, not just about the programming language, but how to use it.