# Arduino Programming Part 5: Functions Redux and Intro to Arrays

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## Goals

Create functions for reading the conductivity sensor

- Only one function is needed (only one used at a time)
- Different functions have different features
- Change input data handling by using different functions
- Main program stays largely unchanged

Introduction to arrays

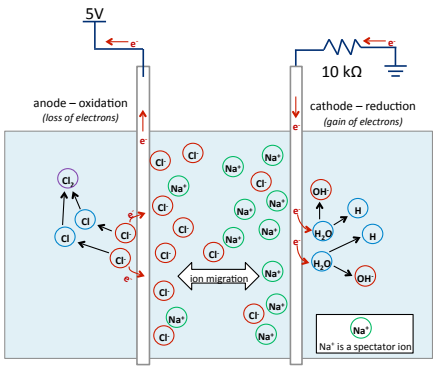
- Use arrays to store readings
- Compute average and standard deviation of the readings



## Measuring salinity

Principle of operation

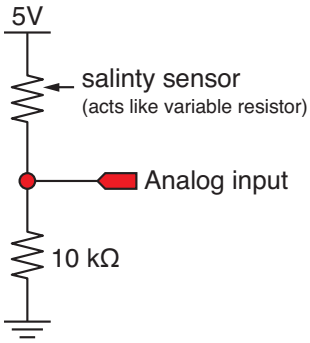
- Ions migrate to electrodes
- Ions exchange electrons with probes, causing current flow.
- Na+ is a spectator ion.
- Ion concentrations increase at electrodes when power is left on.
- Therefore, only turn on power during the time when reading is made. Leave it off otherwise.



# Measuring salinity

Sensor circuit

- It's a voltage divider
- Resistance decreases as salt concentration increases
- Voltage across fixed resistor increases when sensor resistance decreases, i.e. when salt concentration increases





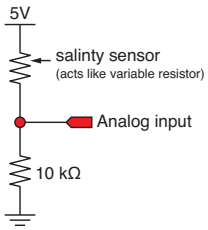

# Study Questions

What is the voltage on the input pin for each of these conditions:

- If the electrical resistance of the water is zero?
- If the electrical resistance of the water is 10kΩ?
- If the electrical resistance of the water is ∞?

What is the input reading for each of those conditions?

IF the resistance varied linearly with salinity, would the voltage vary linearly with salinity?






# Programs for Reading the Salinity Sensor

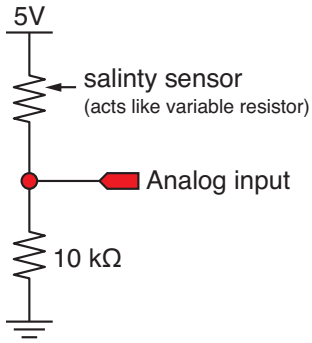
1. Read one value at a time
   - Encapsulate the code in a function so it can be reused
2. Read multiple values and return an average
   - Code in a new function
3. Read multiple values and return average and standard deviation
   - Yet another function
   - Use an array to store readings, then compute statistics
   - Returning two values requires pointers

All three programs use the same circuit

# Measuring salinity

## Measurement algorithm

- Turn on the power by applying 5V to the voltage divider
- Wait for voltage transient to settle
- Read the voltage across fixed resistor
- Turn off the power






# Single reading of conductivity sensor

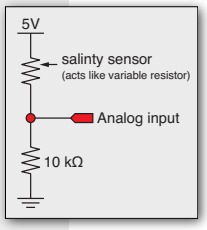
```
int power_pin = 4;   //  Digital I/O pin, Global variable

void setup()
{
  Serial.begin(9600);
  pinMode(power_pin, OUTPUT);
}

void loop()
{
  int input_pin = 2; //  Analog input pin
  int reading;

  digitalWrite( power_pin, HIGH );    //  Turn on sensor
  delay(100);                         //  wait to settle
  reading = analogRead( input_pin );  //  Measure voltage
  digitalWrite( power_pin, LOW );     //  Turn off power

  Serial.println(reading);
}
```






# Create a function to read the sensor

## Why use functions?

- Code in the loop function is just high level commands
  - Overall logic is easier to read and change
  - Reduce likelihood of error as overall code logic changes
- Keep details of sensor-reading contained in the function
  - Variables defined in the function are "local"
  - Details can change, e.g. to increase speed or reduce memory usage without changing the logic of the main function.
  - Reuse the code in other projects: build a library of reusable components

# Use a function to make a single reading

```
int salinity_power_pin = 4;   //  Digital I/O pin, Global variable

void setup()
{
  Serial.begin(9600);
  pinMode(power_pin, OUTPUT);
}

void loop()
{
  int salinity_input_pin = 2; //  Analog input pin
  int salinity;

  salinity = salinity_reading( salinity_power_pin, salinity_input_pin );
  Serial.println(salinity);
}
// ------------------------------------------------------------
int salinity_reading( int power_pin, int input_pin ) {

  int reading;

  digitalWrite( power_pin, HIGH );    //  Turn on the sensor
  delay(100);                         //  Wait to settle
  reading = analogRead( input_pin );  //  Read voltage
  digitalWrite( power_pin, LOW );     //  Turn off the sensor
  return reading;
}
```



# Encapsulate single reading in a function

```
int salinity_power_pin = 4;   //  Digital I/O pin, Global variable

void setup()
{
  Serial.begin(9600);
  pinMode(power_pin, OUTPUT);
}

void loop()
{
  int salinity_input_pin = 2; //  Analog input pin
  int salinity;

  salinity = salinity_reading( salinity_power_pin, salinity_input_pin );
  Serial.println(salinity);
}
// ------------------------------------------------------------
int salinity_reading( int power_pin, int input_pin ) {

  int reading;

  digitalWrite( power_pin, HIGH );    //  Turn on the sensor
  delay(100);                         //  Wait to settle
  reading = analogRead( input_pin );  //  Read voltage
  digitalWrite( power_pin, LOW );     //  Turn off the sensor
  return reading;
}
```

Local variables power_pin and input_pin exist only inside salinity_reading



# Encapsulate single reading in a function

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void setup()
{
  Serial.begin(9600);
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void loop()
{
  int salinity_input_pin = 2; //  Analog input pin
  int salinity;

  salinity = salinity_reading( salinity_power_pin, salinity_input_pin );
  Serial.println(salinity);
}
// ------------------------------------------------------------
int salinity_reading( int power_pin, int input_pin ) {

  int reading;

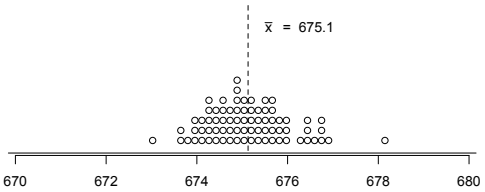
  digitalWrite( power_pin, HIGH );    //  Turn on the sensor
  delay(100);                         //  Wait to settle
  reading = analogRead( input_pin );  //  Read voltage
  digitalWrite( power_pin, LOW );     //  Turn off the sensor
  return reading;
}
```

Value of the local variable called "reading" is returned and stored in the variable called "salinity.

## Improve the function: Average several readings

Average is a measure of central tendency

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$



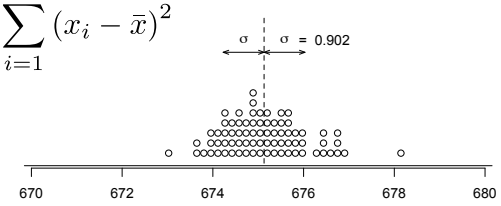



## Improve the function: Compute standard deviation

Standard deviation is a measure of spread

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$






## First improvement: Average several readings

*This loop() function does not need to know the details*

```
int salinity_power_pin = 4;   //  Digital I/O pin, Global variable

void setup()
{
  Serial.begin(9600);
  pinMode(power_pin, OUTPUT);
}

void loop()
{
  int salinity_input_pin = 2; //  Analog input pin
  int nave = 20;              //  Number of readings to average
  float salinity;             //  Float stores fractional reading from computed average

  salinity = salinity_reading_average( salinity_power_pin, salinity_input_pin, nave );
  Serial.println(salinity);
}
```

# First improvement: Average several readings

*Details are hidden in read_salinity_average*

```
float salinity_reading_average( int power_pin, int input_pin, int nave ) {

  int   i;
  float reading, sum;  //  Use floats for more precision and to prevent overflow of sum

  sum = 0.0;
  for ( i=1; i<=nave; i++ ) {

    digitalWrite( power_pin, HIGH );  //  Supply power to the sensor
    delay(100);                       //  Wait for sensor to settle
    sum += analogRead( input_pin );   //  Add reading to the running sum
    digitalWrite( power_pin, LOW );   //  Turn off power to the sensor
    delay(10);                        //  wait between readings

  }

  reading = sum/float(nave);
  return reading;
}
```



# Compute average and standard deviation

Code is more complex

- C functions can only "return" one value
- C functions can modify inputs that are passed by address
- The address of a variable is its location in memory
- The address can be assigned to another variable called a pointer
- Pointers are challenging for the beginner



# A simple example of pointers

```
void loop() {

  int x = 2;
  int y;

  change_value(x, &y);
}


// ---------------------------------

void change_value( int a, int *b ) {

  *b = 2*a;
}
```

Pass the *value of* x into the function

Pass the *address of* y into the function

# A simple example of pointers

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void loop() {

  int x = 2;
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void change_value( int a, int *b ) {

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Pass the *value of* x into the function

Pass the *address of* y into the function

*b is the *pointer to* (the address of) the second input argument

change what is stored in *b



# A simple example of pointers

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void loop() {

  int x = 2;
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  change_value(x, &y);
}


// ----------------------------------

void change_value( int a, int *b ) {

  *b = 2*a;
}
```

Pass the *value of* x into the function

Pass the *address of* y into the function

*b is the *pointer to* (the address of) the second input argument

change what is stored in *b

**Note:** `change_value` does not return a value — its return type is `void`. When `change_value(x,&y)` is executed, the value stored in `y` is changed.



# Compute average and standard deviation

```
void salinity_reading_stats( int power_pin, int input_pin, int nave, float *ave, float *stdev ) {

  int    i, n;
  float  sum;                     //  Use a float to prevent overflow
  float reading[BUFFER_LENGTH];   //  Array to store readings

  n = min( nave, BUFFER_LENGTH );   //  Make sure we don't over-run the data buffer

  // -- Store readings in an array
  for ( i=0; i<n; i++ ) {                 //  First array index is 0, last is n-1
    digitalWrite( power_pin, HIGH );      //  Supply power to the sensor
    delay(100);                           //  Wait for sensor to settle
    reading[i] = analogRead( input_pin );  //  Add reading to the running sum
    digitalWrite( power_pin, LOW );       //  Turn off power to the sensor
    delay(10);                            //  wait between readings
  }

  // -- Compute average and standard deviation.
  for ( sum=0.0, i=0; i<n; i++ )  {
    sum += reading[i];
  }
  *ave =  sum/float(nave);

  for ( sum=0.0, i=0; i<n; i++ ) {
    sum += pow(reading[i] - *ave, 2);
  }
  *stdev = sqrt( sum/float(n-1) );
}
```

# Use salinity_reading_stats

```
int salinity_power_pin = 4;   //  Digital I/O pin

#define  BUFFER_LENGTH  100   //  Size of array to store readings for computation of ave and stdev
                              //  Reduce BUFFER_LENGTH to save memory if statistics are OK
                              //  with smaller sample size
void setup()
{
  Serial.begin(9600);
  pinMode(salinity_power_pin, OUTPUT);
}

void loop()
{
  int   salinity_input_pin = 2;
  int   nave = 20;
  float ave, stdev;

  salinity_reading_stats( salinity_power_pin, salinity_input_pin, nave, &ave, &stdev);

  Serial.print(ave);  Serial.print(", ");   Serial.println(stdev);
}
```

Pass the *address of* ave and *address of* stdev

Use ave and stdev as normal variables

Learning C++ Pointers for REAL Dummies
http://alumni.cs.ucr.edu/~pdiloren/C++_Pointers/