# STATISTICAL ECOLOGY
## Stat 555

*Analysis of variance*

**PURPOSE**: To determine if mean shell lengths of turban snails (*Tegula funebralis*) differ between two sampling years.
**DATA**: n=400 snails were sampled at Yaquina Head OR in 1989 and 1990 and their shell diameter was recorded in mm's.

**ASSUMPTIONS**:
1. Random sampling
2. Data normally distributed
3. $\alpha = 0.05$

$H_o$: $\mu_1 = \mu_2$
$H_A$: $\mu_1 \neq \mu_2$
**TEST STATISTIC**: t=-1.81
**CRITICAL VALUE**: ($\alpha(2)$=0.05 and df=798) = 1.963
**CONCLUSION**: |-1.81| < 1.963 so <u>cannot</u> <u>reject</u> null hypothesis
**BIOLOGICAL INTERPRETATION**: shell lengths are not significantly different between years.

```
MTB > TwoSample 95.0 'Tegula89' 'Tegula90';
SUBC>   Alternative 0;
SUBC>   Pooled.

TWOSAMPLE T FOR Tegula89 VS Tegula90
            N      MEAN     STDEV   SE MEAN
Tegula89  400     17.59      3.39      0.17
Tegula90  400     18.02      3.41      0.17

95 PCT CI FOR MU Tegula89 - MU Tegula90: (-0.91, 0.04)

TTEST MU Tegula89 = MU Tegula90 (VS NE): T= -1.81  P=0.071  DF=  798

POOLED STDEV =       3.40
```

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```
MTB > aovo c1 c2

ANALYSIS OF VARIANCE
SOURCE     DF        SS        MS        F        p
FACTOR      1      37.8      37.8     3.28    0.071
ERROR     798    9220.5      11.6
TOTAL     799    9258.4
                                 INDIVIDUAL 95 PCT CI'S FOR MEAN
                                 BASED ON POOLED STDEV
 LEVEL      N      MEAN     STDEV  -----+---------+---------+---------+-
Tegula89  400    17.590     3.393  (----------*----------)
Tegula90  400    18.025     3.406              (----------*----------)
                                   -----+---------+---------+---------+-
POOLED STDEV =    3.399               17.40     17.70     18.00     18.30
```

**ASSUMPTIONS**:
1. Random sampling
2. Data normally distributed
3. Sample variances equal
4. $\alpha = 0.05$

$H_o$: $\mu_1 = \mu_2$
$H_A$: $\mu_1 \neq \mu_2$
**TEST STATISTIC**: F=3.28
**CRITICAL VALUE**: ($\alpha(1)$=0.05 and df=1,500) = 3.86
**CONCLUSION**: 3.28 < 3.86 so <u>cannot</u> <u>reject</u> null hypothesis
**BIOLOGICAL INTERPRETATION**: shell lengths are not significantly different between years.

**PURPOSE**: To determine if the number of basal teeth of snakehead cowries differ between three populations.
**DATA**: n=30 cowries were sampled on Hawaii(Oahu), Fiji, and Easter Island and the number of basal teeth was counted.

**ASSUMPTIONS**:
1. Random sampling
2. Data normally distributed
3. Sample variances equal
4. $\alpha = 0.05$

```
MTB > AOVO C1 C2 C3

ANALYSIS OF VARIANCE
SOURCE       DF        SS         MS        F        p
FACTOR        2    26.600     13.300    20.70    0.000
ERROR        87    55.900      0.643
TOTAL        89    82.500
                                       INDIVIDUAL 95 PCT CI'S FOR MEAN
                                       BASED ON POOLED STDEV
 LEVEL        N      MEAN      STDEV   -----+---------+---------+---------+-
EASTER       30    12.067      0.785    (----*-----)
FIJI         30    12.167      0.791      (----*-----)
HAWAII       30    13.267      0.828                              (----*-----)
                                       -----+---------+---------+---------+-
POOLED STDEV =      0.802                 12.00     12.50     13.00     13.50
```

$H_o$: $\mu_1 = \mu_2 = \mu_3$
$H_A$: at least one $\mu$ not equal
**TEST STATISTIC**: F=20.7
**CRITICAL VALUE**: ($\alpha(1)$=0.05 and df=2,87) = 3.11
**CONCLUSION**: 20.7 > 3.11 so <u>reject</u> null hypothesis
**BIOLOGICAL INTERPRETATION**: at least one sample has a significantly different number of basal teeth. Based on 95% confidence intervals it appears that shells from Hawaii have more teeth than shells from Fiji and Easter Island, which are probably not different.

STATISTICAL ECOLOGY
Stat 555

*Two-way analysis of variance*

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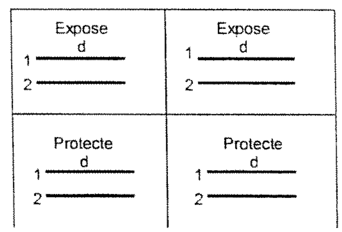
**EXAMPLE 1**: ABSIZE.MPJ

Purpose: to determine if abalone size varies along wave-exposure gradients in two populations, Santa Cruz Island and Año Nuevo Island, California.

Data: Shell lengths of black abalone (*Haliotis cracherodii*) were measured in mm's at two populations, at two wave exposure regimes at each population, and on two transects at each wave-exposure regime.

Population 1 Population 2

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ONE-WAY ANALYSIS OF VARIANCE

$H_0$: $\mu_1 = \mu_2$ for population (Santa Cruz vs. Año Nuevo)

$H_A$: $\mu_1 \neq \mu_2$ for population

```
MTB > anova size = pop;
SUBC> means pop.

Factor      Type Levels Values
Pop        fixed      2      1      2

Analysis of Variance for Size

Source       DF        SS         MS        F        P
Pop           1     28276      28276    60.81    0.000
Error       158     73470        465
Total       159    101746

     MEANS

 Pop     N       Size
   1    80      98.18
   2    80     124.76
```

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PARTIAL TWO-WAY ANALYSIS OF VARIANCE

$H_0$: $\mu_1 = \mu_2$ for population (Santa Cruz vs. Año Nuevo)

$H_0$: $\mu_1 = \mu_2$ for wave exposure (Exposed vs. protected)

$H_A$: $\mu_1 \neq \mu_2$ for population

$H_A$: $\mu_1 \neq \mu_2$ for wave exposure

```
MTB > ANOVA 'Size' = pop wave;
SUBC>   Means Pop Wave.

Factor      Type Levels Values
Pop        fixed      2      1      2
Wave       fixed      2      1      2
```

```
Analysis of Variance for Size

Source        DF        SS          MS       F       P
Pop            1     28276       28276   61.22   0.000
Wave           1       956         956    2.07   0.152
Error        157     72515         462
Total        159    101746

MEANS

 Pop    N      Size
   1   80     98.18
   2   80    124.76

 Wave    N      Size
    1   80    113.91
    2   80    109.03
```

---

COMPLETE TWO-WAY ANALYSIS OF VARIANCE

$H_0$: $\mu_1 = \mu_2$ for population

$H_0$: $\mu_1 = \mu_2$ for wave exposure

$H_0$: no population & wave exposure interaction

$H_A$: $\mu_1 \neq \mu_2$ for population

$H_A$: $\mu_1 \neq \mu_2$ for wave exposure

$H_A$: interaction between population & wave exposure

```
MTB > ANOVA 'Size' = pop wave pop*wave;
SUBC>   Means Pop Wave.

Factor      Type Levels Values
Pop        fixed      2      1      2
Wave       fixed      2      1      2

Analysis of Variance for Size

Source        DF          SS          MS       F       P
Pop            1     28275.8     28275.8   61.12   0.000
Wave           1       955.5       955.5    2.07   0.153
Pop*Wave       1       339.3       339.3    0.73   0.393
Error        156     72175.2       462.7
Total        159    101745.8
```

---

**EXAMPLE 2**: OTTER2.MPJ

Purpose: to determine if sea otter skull size varies among males and females in two populations: California and Alaska.

Data: skull widths of sea otters (*Enhydra lutris*) were measured in mm's at two populations, and sex was identified.

$H_0$: $\mu_1 = \mu_2$ for population

$H_0$: $\mu_1 = \mu_2$ for sex

$H_0$: no interaction between population & sex

$H_A$: $\mu_1 \neq \mu_2$ for population

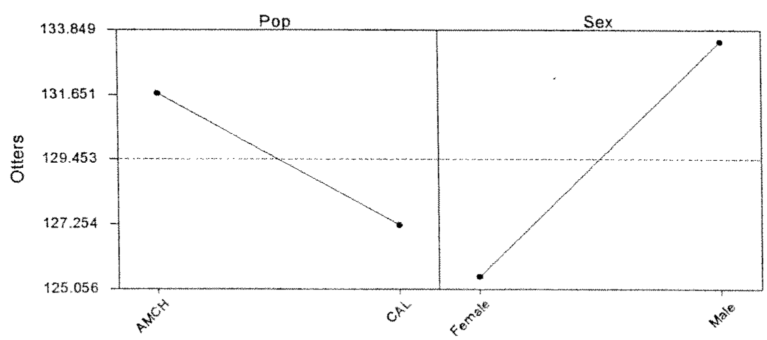
$H_A$: $\mu_1 \neq \mu_2$ for sex

$H_A$: interaction between population & sex

```
MTB > anova data = sex pop sex*pop;
SUBC> means sex*pop.

Factor      Type Levels Values
Sex        fixed      2      1      2
Pop        fixed      2      1      2

Analysis of Variance for Data

Source        DF          SS          MS       F       P
Sex            1     1272.01     1272.01   94.85   0.000
Pop            1      400.51      400.51   29.86   0.000
Sex*Pop        1        0.11        0.11    0.01   0.927
```

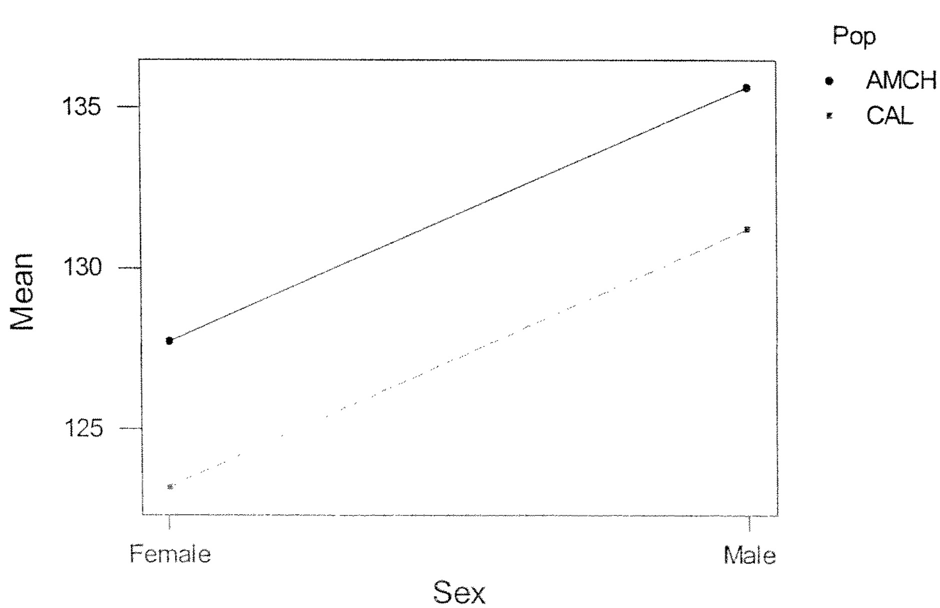
```
Error        76     1019.25       13.41
Total        79     2691.89

     MEANS

 Sex  Pop      N       Data
   1    1     20     135.65
   1    2     20     131.25
   2    1     20     127.75
   2    2     20     123.20


MTB > %Main 'Pop' 'Sex';
SUBC>    Response 'Otters'.
```

Main Effects Plot - Data Means for Otters




```
MTB > %Interact 'Pop' 'Sex';
SUBC>    Response 'data'.
```

Interaction Plot - Data Means for Otters



**EXAMPLE 3**: CALLINASSA.MPJ

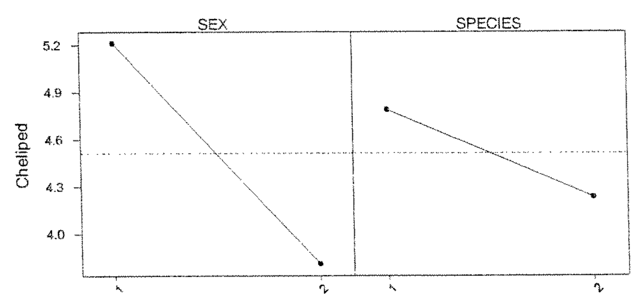
Purpose: to determine if cheliped size varies among males and females of two species of mud shrimp.

Data: cheliped widths of two species of mud shrimp (*Callianassa californiensis* and *C. gigas*) were measured in mm's and sex was identified at Bahia San Quintin, Baja California, Mexico

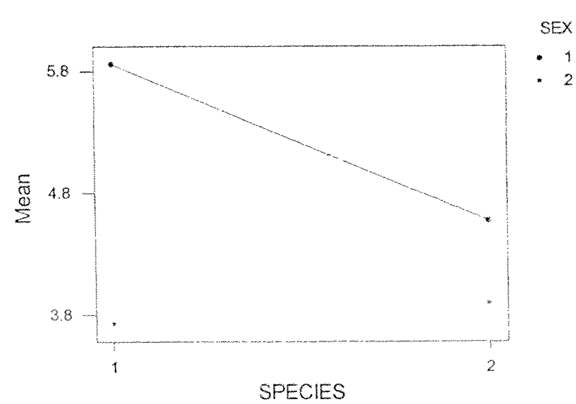
$H_0$: $\mu_1 = \mu_2$ for species
$H_0$: $\mu_1 = \mu_2$ for sex
$H_0$: no interaction between species & sex
$H_A$: $\mu_1 \neq \mu_2$ for species
$H_A$: $\mu_1 \neq \mu_2$ for sex
$H_A$: interaction between species & sex

```
MTB > anova cheliped=sex|species;
SUBC> means sex|species.

Factor      Type Levels Values
SEX        fixed      2      1      2
SPECIES    fixed      2      1      2

Analysis of Variance for CHELIPED

Source          DF         SS        MS       F       P
SEX              1     78.722    78.722   48.36   0.000
SPECIES          1     12.427    12.427    7.63   0.006
SEX*SPECIES      1     21.003    21.003   12.90   0.000
Error          156    253.935     1.628
Total          159    366.088

    MEANS

 SEX     N     CHELIPED
   1    80     5.2133
   2    80     3.8104

 SPECIES     N     CHELIPED
       1    80     4.7905
       2    80     4.2331

 SEX  SPECIES      N     CHELIPED
   1        1     40     5.8542
   1        2     40     4.5722
   2        1     40     3.7267
   2        2     40     3.8940

MTB > %Main 'SEX' 'SPECIES';
SUBC>   Response 'Cheliped'

MTB > %Interact 'SEX' 'SPECIES';
SUBC>   Response 'Cheliped'.
```

Main Effects Plot - Data Means for Cheliped




Interaction Plot - Data Means for Cheliped



**EXAMPLE 4**: ANTHROPLEURA.MPJ

Purpose: to determine if sea anemone size varied among wave exposed and wave-protected habitats at two different locations.

Data: diameter of anemones (*Anthopleura xanthogrammica*) was measured in mm's at wave-exposed and wave-protected areas in light and dark habitats at two sites at Yaquina Head, Oregon.

```
MTB > GLM 'Data' = Wave! Light;
SUBC>   Brief 2 .
```

$H_0$: $\mu_1 = \mu_2$ for exposure
$H_0$: $\mu_1 = \mu_2$ for light
$H_0$: no interaction between exposure & light
$H_A$: $\mu_1 \neq \mu_2$ for exposure
$H_A$: $\mu_1 \neq \mu_2$ for light
$H_A$: interaction between exposure & light

**General Linear Model: Data versus Wave, Light**

| Factor | Type | Levels | Values |
|---|---|---|---|
| Wave | fixed | 2 | Exposed Protected |
| Light | fixed | 2 | Dark Light |

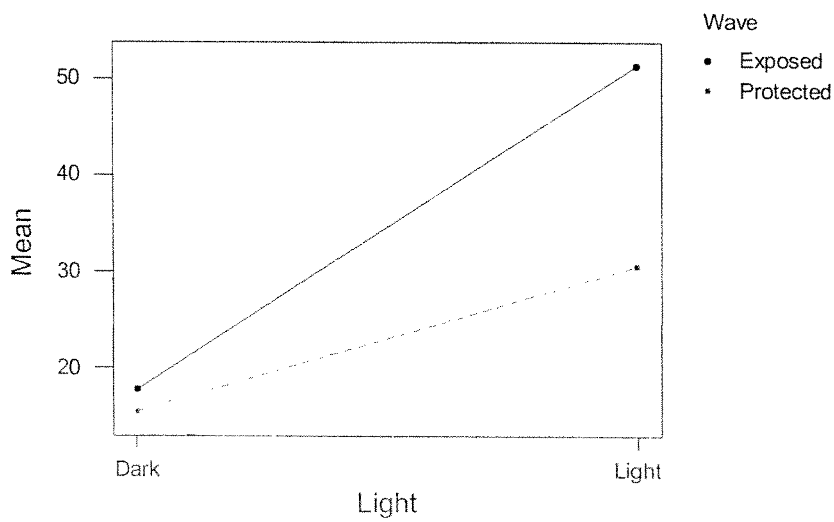
Analysis of Variance for Data, using Adjusted SS for Tests

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Wave | 1 | 6636 | 6636 | 6636 | 43.16 | 0.000 |
| Light | 1 | 29573 | 29573 | 29573 | 192.37 | 0.000 |
| Wave*Light | 1 | 4287 | 4287 | 4287 | 27.89 | 0.000 |
| Error | 196 | 30131 | 30131 | 154 | | |
| Total | 199 | 70627 | | | | |

Unusual Observations for Data

| Obs | Data | Fit | SE Fit | Residual | St Resid |
|---|---|---|---|---|---|
| 2 | 25.000 | 51.320 | 1.753 | -26.320 | -2.14R |
| 3 | 25.000 | 51.320 | 1.753 | -26.320 | -2.14R |
| 7 | 95.000 | 51.320 | 1.753 | 43.680 | 3.56R |
| 8 | 77.000 | 51.320 | 1.753 | 25.680 | 2.09R |
| 10 | 25.000 | 51.320 | 1.753 | -26.320 | -2.14R |

Interaction Plot - Data Means for Data



**EXAMPLE 5**: QUEST.MPJ

Purpose: to determine if coral abundance varied among years and depths at Puako, Hawaii.

Data: total percent coral cover was estimated from 0.25 $m^2$ quadrats at 10, 25 and 40 foot depths at Puako Hawaii in May of 1992, 1993 and 1994 (QUEST).

```
MTB > glm coral=year|depth;
SUBC> means year|depth.

Factor    Levels Values
Year           3      1      2      3
Depth          3      1      2      3
```

$H_0$: $\mu_1 = \mu_2 = \mu_3$ for years
$H_0$: $\mu_1 = \mu_2 = \mu_3$ for depths
$H_0$: no interaction between years & depths
$H_A$: $\mu_1 \neq \mu_2 \neq \mu_3$ for years
$H_A$: $\mu_1 \neq \mu_2 \neq \mu_3$ for depths
$H_A$: interaction between years & depths

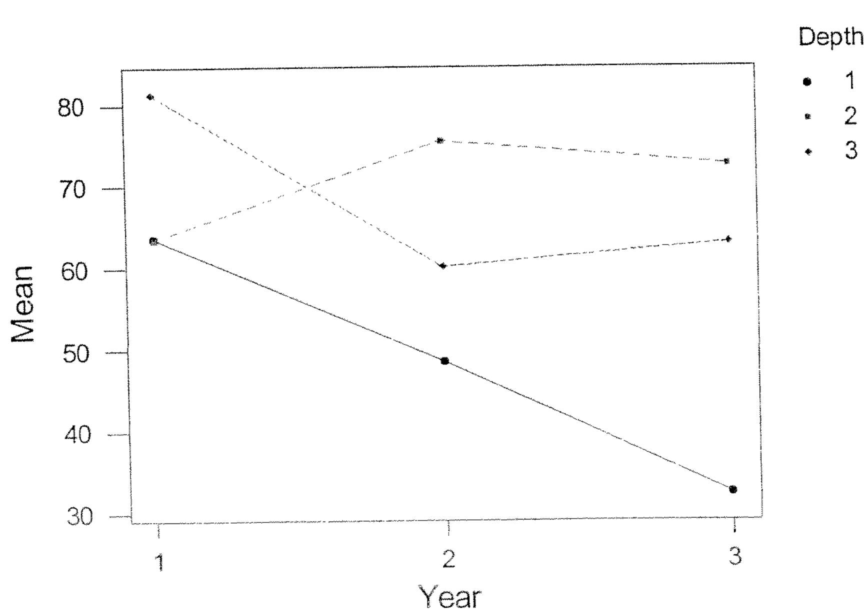
Analysis of Variance for Coral

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Year | 2 | 5143.6 | 4721.5 | 2360.8 | 2.70 | 0.070 |
| Depth | 2 | 16953.7 | 16889.0 | 8444.5 | 9.66 | 0.000 |
| Year*Depth | 4 | 9934.1 | 9934.1 | 2483.5 | 2.84 | 0.026 |
| Error | 154 | 134569.7 | 134569.7 | 873.8 | | |
| Total | 162 | 166601.1 | | | | |

Unusual Observations for Coral

| Obs. | Coral | Fit | Stdev.Fit | Residual | St.Resid |
|---|---|---|---|---|---|
| 4 | 0.000 | 63.610 | 6.610 | -63.610 | -2.21R |
| 28 | 0.000 | 63.529 | 7.169 | -63.529 | -2.22R |
| 43 | 10.000 | 81.261 | 6.968 | -71.261 | -2.48R |
| 76 | 16.700 | 75.514 | 6.451 | -58.814 | -2.04R |
| 77 | 5.500 | 75.514 | 6.451 | -70.014 | -2.43R |
| 80 | 7.500 | 75.514 | 6.451 | -68.014 | -2.36R |
| 144 | 2.500 | 72.628 | 6.968 | -70.128 | -2.44R |

Interaction Plot - Data Means for Coral



*Analysis of variance*

```
MTB > Oneway 'Length' 'Pop/sex';
SUBC>   Tukey 5.
```

## One-way ANOVA: Length versus Pop/sex

```
Source   DF      SS     MS      F      P
Pop/sex   3  1672.6  557.5  41.57  0.000
Error    76  1019.2   13.4
Total    79  2691.9

S = 3.662   R-Sq = 62.14%   R-Sq(adj) = 60.64%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level    N    Mean  StDev  ------+---------+---------+---------+---
AMCH_F  20  127.75   2.83            (---*---)
AMCH_M  20  135.65   4.07                                (---*---)
CAL_F   20  123.20   3.59  (---*---)
CAL_M   20  131.25   4.02                     (---*---)
                           ------+---------+---------+---------+---
                             124.0     128.0     132.0     136.0

Pooled StDev = 3.66


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Pop/sex

Individual confidence level = 98.97%


Pop/sex = AMCH_F subtracted from:

Pop/sex   Lower  Center   Upper  ---------+---------+---------+---------+
AMCH_M    4.854   7.900  10.946                        (---*---)
CAL_F    -7.596  -4.550  -1.504          (--*---)
CAL_M     0.454   3.500   6.546                    (--*---)
                                 ---------+---------+---------+---------+
                                       -8.0       0.0       8.0      16.0


Pop/sex = AMCH_M subtracted from:

Pop/sex    Lower   Center   Upper  ---------+---------+---------+---------+
CAL_F    -15.496  -12.450  -9.404  (--*---)
CAL_M     -7.446   -4.400  -1.354            (---*--)
                                   ---------+---------+---------+---------+
                                         -8.0       0.0       8.0      16.0


Pop/sex = CAL_F subtracted from:

Pop/sex  Lower  Center   Upper  ---------+---------+---------+---------+
CAL_M    5.004   8.050  11.096                         (---*---)
                                ---------+---------+---------+---------+
                                      -8.0       0.0       8.0      16.0
```