ctz-euclide

Typst Port

Euclidean Geometry for Typst

A comprehensive geometry package built on CeTZ

Version 0.1.5

Nathan Scheinmann

Contents

1. Introduction

`ctz-euclide` is a geometry package for Typst, a port of the LaTeX package `tkz-euclide`. Built on top of CeTZ (a powerful drawing library), it provides high-level constructions for Euclidean geometry.

1.1. Features

- **Point Registry**: Define points once, reference them by name throughout your figure
- **Geometric Constructions**: Perpendiculars, parallels, bisectors, mediators
- **Intersections**: Line–line, line–circle, circle–circle with multiple solution handling
- **Triangle Centers**: Centroid, circumcenter, incenter, orthocenter, and 10+ specialized centers
- **Special Triangles**: Medial, orthic, intouch triangles
- **Transformations**: Rotation, reflection, translation, homothety, projection, inversion
- **Drawing & Styling**: Points, labels, angles, segments with tick marks
- **Grid & Axes**: Coordinate systems with customizable appearance
- **Clipping**: Mathematical line clipping for clean bounded figures

1.2. Installation

Import the package in your Typst document:

```
#import "@preview/ctz-euclide:0.1.0": *
```

All figures use the `ctz-canvas` function (re-exported from CeTZ):

```
#ctz-canvas({
  import cetz.draw: *
  ctz-init()

  // Your geometry code here
})
```

Naming notes:

- All public functions are prefixed with `ctz-` to avoid conflicts.
- Point creation and drawing use `ctz-def-points` and `ctz-draw-points`.
- Other constructors use `ctz-def-*`, and drawing utilities use `ctz-draw-*`.

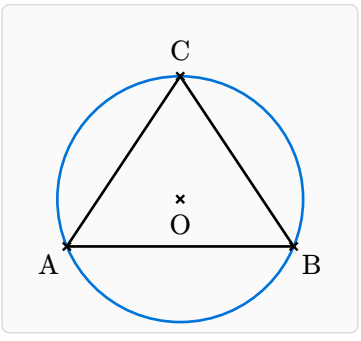
The `ctz-init()` call initializes the point registry and coordinate resolver.

1.3. Basic Usage

Code

```
#ctz-canvas(length: 0.8cm, {
  import cetz.draw: *
  ctz-init()

  // Define points
  ctz-def-points(A: (0, 0), B: (4, 0), C: (2, 3))

  // Draw triangle
  ctz-draw(line: ("A", "B", "C", "A"), stroke: black)

  // Find circumcenter and draw circumcircle
  ctz-def-circumcenter("O", "A", "B", "C")
  ctz-draw(circle-through: ("O", "A"), stroke: blue)

  // Draw and label points
  ctz-draw(points: ("A", "B", "C", "O"), labels: (
    A: "below left", B: "below right",
    C: "above", O: "below"))
})
```

Figure



2. Core Concepts

2.1. The Point Registry

The point registry is the heart of `ctz-euclide`. Once you define a point with a name, that name can be used directly in CeTZ drawing commands.

```
ctz-def-points(A: (0, 0), B: (3, 4))  // Register points A and B
ctz-draw(segment: ("A", "B"))              // Use them directly in CeTZ
```

Under the hood, `ctz-init()` installs a coordinate resolver that translates `"A"` to the stored coordinates.

2.2. Figure Scaling

Control the size of your figures using CeTZ's `length` parameter:

```
#ctz-canvas(length: 0.8cm, { ... })
```

This scales everything proportionally, including stroke widths. Typical values:

- `0.6cm` – small inline figures
- `0.8cm` – standard examples
- `1.0cm` – large detailed figures

2.3. Coordinate Systems

Points can be defined in multiple ways:

```
// Explicit coordinates
ctz-def-points(A: (2, 3))

// Using existing CeTZ coordinates
ctz-def-points(B: (rel: (1, 1), to: "A"))

// Mixed: numbers and existing points
ctz-def-points(C: (4, 0), D: "A", E: (3, 2))
```

3. Point Definitions

3.1. Basic Points — `ctz-def-points`

Define one or more points at specific coordinates:

```
ctz-def-points(A: (0, 0), B: (4, 0), C: (2, 3))
```

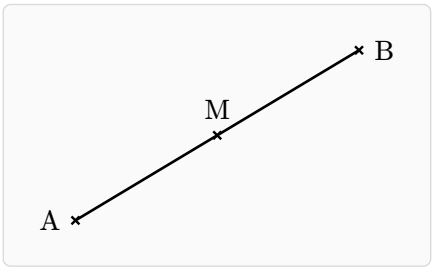
3.2. Midpoint — `ctz-def-midpoint`

Find the midpoint of a segment:

Code

```
#ctz-canvas(length: 0.8cm, {
  import cetz.draw: *
  ctz-init()

  ctz-def-points(A: (0, 0), B: (5, 3))
  ctz-def-midpoint("M", "A", "B")

  ctz-draw(segment: ("A", "B"), stroke: black)
  ctz-draw(points: ("A", "B", "M"), labels: (
    A: "left", B: "right", M: "above"))
})
```

Figure



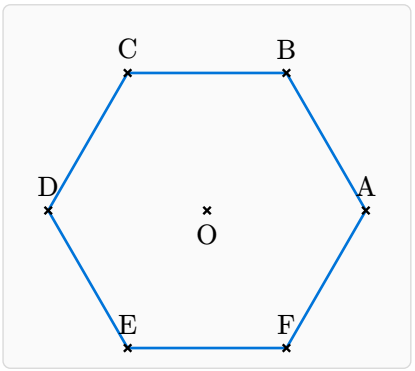
3.3. Regular Polygons — `ctz-def-regular-polygon`

Generate vertices of a regular n-gon. If you pass a polygon name first, it is registered and can be drawn/labeled by name: You can also mark all sides during drawing with `mark` and optional `mark-opts`.

Code

```
#ctz-canvas(length: 0.7cm, {
  import cetz.draw: *
  ctz-init()

  ctz-def-points(O: (0, 0), A: (3, 0))
  // O is the center; A is the starting vertex that
fixes the radius/angle.
  ctz-def-regular-polygon("Hex", ("A", "B", "C", "D",
"E", "F"), "O", "A")

  ctz-draw("Hex", stroke: blue)
  ctz-draw(points: ("A", "B", "C", "D", "E", "F",
"O"), labels: (O: "below"))
})
```

Figure



3.4. Named Polygons — `ctz-def-polygon` / `ctz-label-polygon`

Define a polygon once and draw/label it by name:

```
ctz-def-points(A: (0, 0), B: (4, 0), C: (4, 2), D: (0, 2))
ctz-def-polygon("P1", "A", "B", "C", "D")
ctz-draw("P1", stroke: black)
ctz-label-polygon("P1", $P_1$, pos: "center")
```

3.5. Linear Combination — `ctz-def-linear`

Define a point along a line: $P = A + k(B - A)$

```
ctz-def-linear("P", "A", "B", 0.3)  // P is 30% from A to B
ctz-def-linear("Q", "A", "B", 1.5)  // Q extends beyond B
```

4. Line Constructions

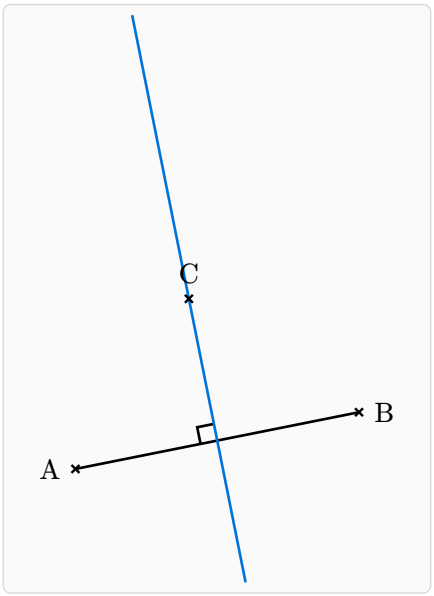
4.1. Perpendicular — `ctz-def-perp`

Construct a perpendicular line through a point:

Code

```
#ctz-canvas(length: 0.75cm, clip-canvas: (-0.5, -0.5,
5.5, 3.5), {
  import cetz.draw: *
  ctz-init()

  ctz-def-points(A: (0, 0), B: (5, 1), C: (2, 3))
  ctz-def-perp("P1", "P2", ("A", "B"), "C")
  ctz-def-project("H", "C", "A", "B")

  ctz-draw(segment: ("A", "B"), stroke: black)
  ctz-draw(segment: ("P1", "P2"), stroke: blue)
  ctz-draw-mark-right-angle("A", "H", "C", size: 0.3)

  ctz-draw(points: ("A", "B", "C"), labels: (
    A: "left", B: "right", C: "above"))
})
```

Figure



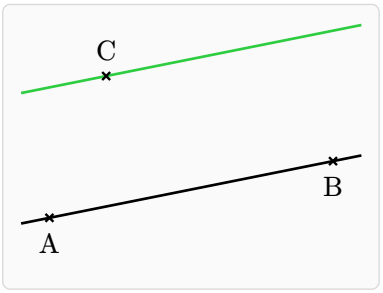
4.2. Parallel — `ctz-def-para`

Construct a parallel line through a point:

Code

```
#ctz-canvas(length: 0.75cm, clip-canvas: (-0.5, -0.5,
5.5, 3.5), {
  import cetz.draw: *
  ctz-init()

  ctz-def-points(A: (0, 0), B: (5, 1), C: (1, 2.5))
  ctz-def-para("P1", "P2", ("A", "B"), "C")

  ctz-draw-line-add("A", "B", add: (2, 2), stroke:
black)
  ctz-draw-line-add("P1", "P2", add: (2, 2), stroke:
green)

  ctz-draw(points: ("A", "B", "C"), labels: (
    A: "below",
    B: "below",
    C: "above"
  ))
})
```

Figure



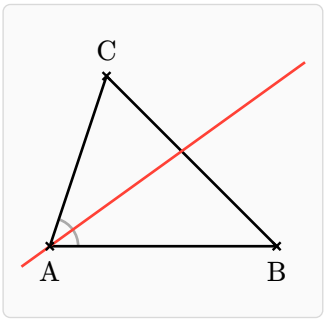
4.3. Angle Bisector — `ctz-def-bisect`

Construct the bisector of an angle:

Code

```
#ctz-canvas(length: 0.8cm, clip-canvas: (-0.5, -0.5,
4.5, 3.5), {
  import cetz.draw: *
  ctz-init()

  ctz-def-points(A: (0, 0), B: (4, 0), C: (1, 3))
  ctz-def-bisect("D1", "D2", "C", "A", "B")

  ctz-draw(line: ("A", "B", "C", "A"), stroke: black)
  ctz-draw-segment("D1", "D2", stroke: red)

  ctz-draw-angle("A", "C", "B", radius: 0.5, stroke:
gray)
  ctz-draw(points: ("A", "B", "C"), labels: (
    A: "below",
    B: "below",
    C: "above"
  ))
})
```

Figure



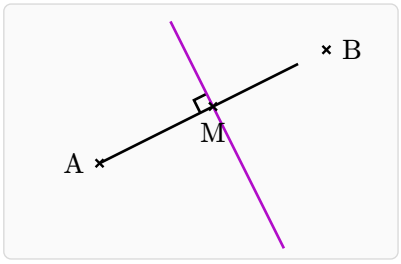
4.4. Perpendicular Bisector — `ctz-def-mediator`

Construct the perpendicular bisector of a segment:

Code

```
#ctz-canvas(length: 0.75cm, clip-canvas: (-0.5, -0.5,
4.5, 3.5), {
  import cetz.draw: *
  ctz-init()

  ctz-def-points(A: (1, 1), B: (5, 3))
  ctz-def-mediator("M1", "M2", "A", "B")
  ctz-def-midpoint("M", "A", "B")

  ctz-draw(segment: ("A", "B"), stroke: black)
  ctz-draw(segment: ("M1", "M2"), stroke: purple)
  ctz-draw-mark-right-angle("M1", "M", "A", size:
0.25)

  ctz-draw(points: ("A", "B", "M"), labels: (
    A: "left",
    B: "right",
    M: "below"
  ))
})
```

Figure



5. Intersections

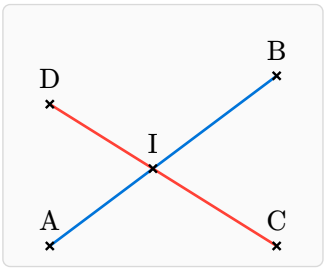
5.1. Line–Line — `ctz-def-ll`

Find the intersection of two lines:

Code

```
#ctz-canvas(length: 0.8cm, {
  import cetz.draw: *
  ctz-init()

  ctz-def-points(A: (0, 0), B: (4, 3),
            C: (4, 0), D: (0, 2.5))
  ctz-def-line("L1", "A", "B")
  ctz-def-line("L2", "C", "D")
  ctz-def-ll("I", "L1", "L2")

  ctz-draw("L1", stroke: blue)
  ctz-draw("L2", stroke: red)

  ctz-draw(points: ("A", "B", "C", "D", "I"), labels:
(I: "above"))
})
```

Figure



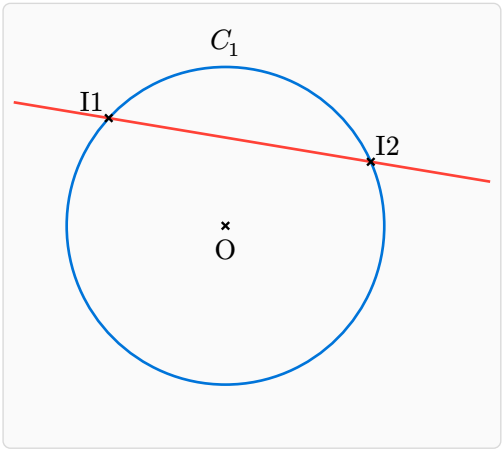
5.2. Line–Circle — `ctz-def-lc`

Find intersections of a line with a circle:

Code

```
#ctz-canvas(length: 0.7cm, clip-canvas: (-4, -4, 5,
4), {
  import cetz.draw: *
  ctz-init()

  ctz-def-points(O: (0, 0), R: (3, 0),
            A: (-2, 2), B: (4, 1))
  ctz-def-line("L1", "A", "B")
  ctz-def-circle("C1", "O", through: "R")
  ctz-def-lc(("I1", "I2"), "L1", "C1")

  ctz-draw("C1", stroke: blue)
  ctz-label-circle("C1", $C_1$, pos: "above", dist:
0.2)
  ctz-draw-line-add("A", "B", add: (2, 2), stroke:
red)

  ctz-draw(points: ("O", "I1", "I2"), labels: (
    O: "below",
    I1: "above left",
    I2: "above right"
  ))
})
```

Figure



Named line/circle form:

```
ctz-def-line("L1", "A", "B")
ctz-def-circle("C1", "O", radius: 3)
ctz-def-lc(("I1", "I2"), "L1", "C1")
```

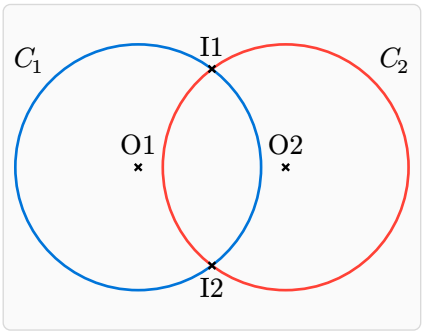
5.3. Circle–Circle — `ctz-def-cc`

Find intersections of two circles:

Code

```
#ctz-canvas(length: 0.65cm, {
  import cetz.draw: *
  ctz-init()

  ctz-def-points(O1: (0, 0), O2: (3, 0),
            R1: (2.5, 0), R2: (5.5, 0))
  ctz-def-circle("C1", "O1", through: "R1")
  ctz-def-circle("C2", "O2", through: "R2")
  ctz-def-cc(("I1", "I2"), "C1", "C2")

  ctz-draw("C1", stroke: blue)
  ctz-draw("C2", stroke: red)
  ctz-label-circle("C1", $C_1$, pos: "above left",
dist: 0.2)
  ctz-label-circle("C2", $C_2$, pos: "above right",
dist: 0.2)

  ctz-draw(points: ("O1", "O2", "I1", "I2"), labels:
(
    I1: "above",
    I2: "below"
  ))
})
```

Figure



Named circle form:

```
ctz-def-circle("C1", "O1", through: "R1")
ctz-def-circle("C2", "O2", through: "R2")
ctz-def-cc(("I1", "I2"), "C1", "C2")
```

6. Triangle Centers

6.1. Basic Centers

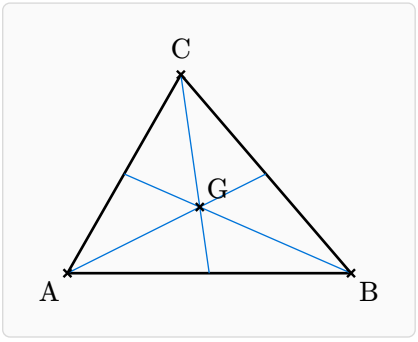
6.1.1. Centroid — `ctz-def-centroid`

The intersection of medians (center of mass):

Code

```
#ctz-canvas(length: 0.8cm, {
  import cetz.draw: *
  ctz-init()

  ctz-def-points(A: (0, 0), B: (5, 0), C: (2, 3.5))
  ctz-def-centroid("G", "A", "B", "C")

  // Draw medians
  ctz-def-midpoint("Ma", "B", "C")
  ctz-def-midpoint("Mb", "A", "C")
  ctz-def-midpoint("Mc", "A", "B")

  ctz-draw(line: ("A", "B", "C", "A"), stroke: black)
  ctz-draw(segment: ("A", "Ma"), stroke: blue +
0.5pt)
  ctz-draw(segment: ("B", "Mb"), stroke: blue +
0.5pt)
  ctz-draw(segment: ("C", "Mc"), stroke: blue +
0.5pt)

  ctz-draw(points: ("A", "B", "C", "G"), labels: (
    A: "below left",
    B: "below right",
    C: "above",
    G: "above right"
  ))
})
```

Figure



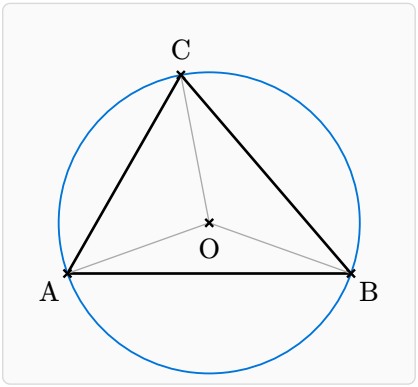
6.1.2. Circumcenter — `ctz-def-circumcenter`

Center of the circumscribed circle:

Code

```
#ctz-canvas(length: 0.75cm, clip-canvas: (-0.5, -0.5,
5.5, 4), {
  import cetz.draw: *
  ctz-init()

  ctz-def-points(A: (0, 0), B: (5, 0), C: (2, 3.5))
  ctz-def-circumcenter("O", "A", "B", "C")

  ctz-draw(line: ("A", "B", "C", "A"), stroke: black)
  ctz-draw(circle-through: ("O", "A"), stroke: blue +
0.7pt)

  ctz-draw(segment: ("O", "A"), stroke: gray + 0.5pt)
  ctz-draw(segment: ("O", "B"), stroke: gray + 0.5pt)
  ctz-draw(segment: ("O", "C"), stroke: gray + 0.5pt)

  ctz-draw(points: ("A", "B", "C", "O"), labels: (
    A: "below left",
    B: "below right",
    C: "above",
    O: "below"
  ))
})
```

Figure



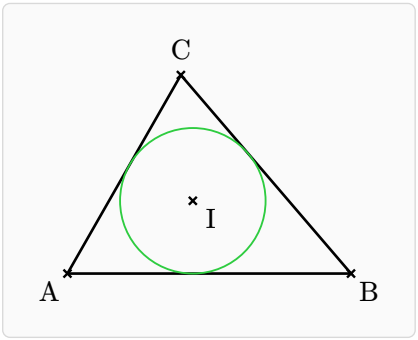
6.1.3. Incenter — `ctz-def-incenter`

Center of the inscribed circle:

Code

```
#ctz-canvas(length: 0.75cm, clip-canvas: (-0.5, -0.5,
5.5, 4), {
  import cetz.draw: *
  ctz-init()

  ctz-def-points(A: (0, 0), B: (5, 0), C: (2, 3.5))
  ctz-def-incenter("I", "A", "B", "C")

  ctz-draw(line: ("A", "B", "C", "A"), stroke: black)
  ctz-draw(incircle: ("A", "B", "C"), stroke: green +
0.7pt)

  ctz-draw(points: ("A", "B", "C", "I"), labels: (
    A: "below left",
    B: "below right",
    C: "above",
    I: "below right"
  ))
})
```

Figure



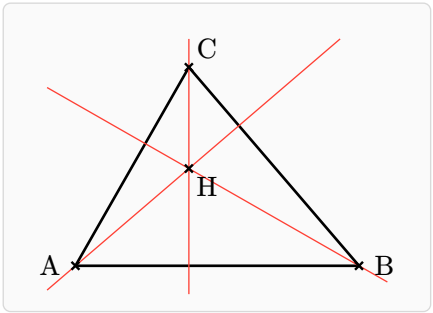
6.1.4. Orthocenter — `ctz-def-orthocenter`

Intersection of altitudes:

Code

```
#ctz-canvas(length: 0.75cm, {
  import cetz.draw: *
  ctz-init()

  ctz-def-points(A: (0, 0), B: (5, 0), C: (2, 3.5))
  ctz-def-orthocenter("H", "A", "B", "C")

  // Altitudes
  ctz-def-perp("Ha1", "Ha2", ("B", "C"), "A")
  ctz-def-perp("Hb1", "Hb2", ("A", "C"), "B")
  ctz-def-perp("Hc1", "Hc2", ("A", "B"), "C")

  ctz-draw(line: ("A", "B", "C", "A"), stroke: black)
  ctz-draw-line-add("A", "Ha1", add: (2, 2), stroke:
red + 0.5pt)
  ctz-draw-line-add("B", "Hb1", add: (2, 2), stroke:
red + 0.5pt)
  ctz-draw-line-add("C", "Hc1", add: (2, 2), stroke:
red + 0.5pt)

  ctz-draw(points: ("A", "B", "C", "H"), labels: (
    A: "left",
    B: "right",
    C: "above right",
    H: "below right"
  ))
})
```

Figure



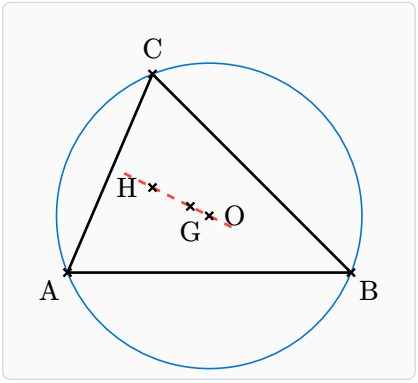
6.2. The Euler Line

In any non-equilateral triangle, the orthocenter H, centroid G, and circumcenter O are collinear. This line is called the **Euler line**, and remarkably, G divides HO in the ratio $2:1$.

Code

```
#ctz-canvas(length: 0.75cm, clip-canvas: (-0.5, -0.5,
5.5, 4), {
  import cetz.draw: *
  ctz-init()

  ctz-def-points(A: (0, 0), B: (5, 0), C: (1.5, 3.5))

  ctz-def-orthocenter("H", "A", "B", "C")
  ctz-def-centroid("G", "A", "B", "C")
  ctz-def-circumcenter("O", "A", "B", "C")

  ctz-draw(line: ("A", "B", "C", "A"), stroke: black)
  ctz-draw-line-add("H", "O", add: 0.5, stroke:
(paint: red, dash: "dashed"))
  ctz-draw(circle-through: ("O", "A"), stroke: blue +
0.6pt)

  ctz-draw(points: ("A", "B", "C", "H", "G", "O"),
labels: (
    A: "below left",
    B: "below right",
    C: "above",
    H: "left",
    G: "below",
    O: "right"
  ))
})
```

Figure



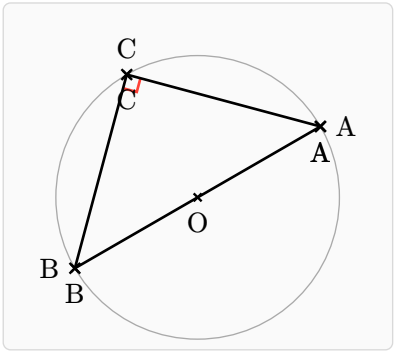
6.3. Right Triangles via Thales' Theorem

Thales' theorem states that any triangle inscribed in a semicircle with the diameter as its base has a right angle at the opposite vertex. The `ctz-def-thales-triangle()` function creates such triangles.

Code

```
#ctz-canvas(length: 0.75cm, {
  import cetz.draw: *
  ctz-init()

  ctz-def-points(O: (0, 0))
  ctz-def-thales-triangle("A", "B", "C", "O", 2.5,
    base-angle: 30, orientation: "left")

  ctz-draw(circle-r: (_pt("O"), 2.5), stroke: gray +
0.5pt)
  ctz-draw-path("A--B--C--A", stroke: black + 1pt)
  ctz-draw-mark-right-angle("A", "C", "B", color:
red)

  ctz-draw(points: ("A", "B", "C", "O"), labels: (
    A: "right",
    B: "left",
    C: "above",
    O: "below"
  ))
})
```

Figure



Parameters:

- `name-a, name-b`: Diameter endpoints (base of triangle)
- `name-c`: Vertex with the right angle
- `center`: Circle center
- `radius`: Circle radius
- `base-angle`: Rotation angle for the diameter (default: 0)
- `orientation`: "left" or "right" - position of right angle vertex

6.4. Advanced Centers

`ctz-euclide` supports 10+ specialized triangle centers:

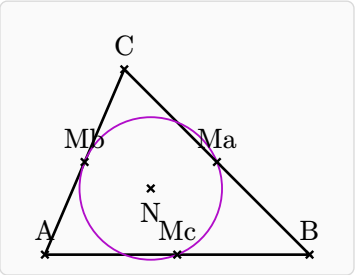
- `ctz-def-lemoine` — Symmedian point (Lemoine point)
- `ctz-def-nagel` — Nagel point
- `ctz-def-gergonne` — Gergonne point
- `ctz-def-spieker` — Spieker center (incenter of medial triangle)
- `ctz-def-euler` — Nine-point circle center
- `ctz-def-feuerbach` — Feuerbach point
- `ctz-def-mittenpunkt` — Mittenpunkt
- `ctz-def-excenter` — Excenter (specify vertex: `"a"`, `"b"`, or `"c"`)

Example with Euler (nine-point) circle:

Code

```
#ctz-canvas(length: 0.7cm, {
  import cetz.draw: *
  ctz-init()

  ctz-def-points(A: (0, 0), B: (5, 0), C: (1.5, 3.5))
  ctz-def-euler("N", "A", "B", "C")

  ctz-draw(line: ("A", "B", "C", "A"), stroke: black)

  // Nine-point circle passes through midpoints
  ctz-def-midpoint("Ma", "B", "C")
  ctz-def-midpoint("Mb", "A", "C")
  ctz-def-midpoint("Mc", "A", "B")

  ctz-draw(circle-through: ("N", "Ma"), stroke:
purple + 0.7pt)

  ctz-draw(points: ("A", "B", "C", "N", "Ma", "Mb",
"Mc"), labels: (
    N: "below"
  ))
})
```

Figure



7. Transformations

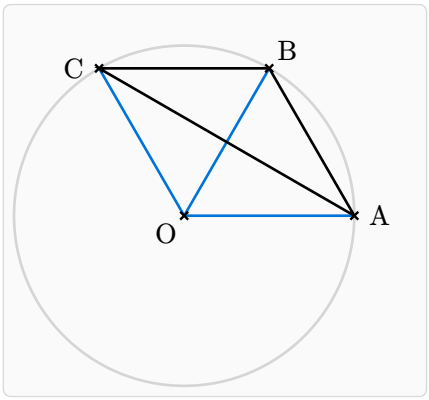
7.1. Rotation — `rotate`

Rotate a point around a center:

Code

```
#ctz-canvas(length: 0.75cm, {
  import cetz.draw: *
  ctz-init()

  ctz-def-points(O: (2, 2), A: (5, 2))
  ctz-def-rotation("B", "A", "O", 60)
  ctz-def-rotation("C", "A", "O", 120)

  ctz-draw(circle-r: (_pt("O"), 3), stroke:
gray.lighten(50%))
  ctz-draw(segment: ("O", "A"), stroke: blue)
  ctz-draw(segment: ("O", "B"), stroke: blue)
  ctz-draw(segment: ("O", "C"), stroke: blue)
  ctz-draw(line: ("A", "B", "C", "A"), stroke: black)

  ctz-draw(points: ("O", "A", "B", "C"), labels: (
    O: "below left",
    A: "right",
    B: "above right",
    C: "left"
  ))
})
```

Figure



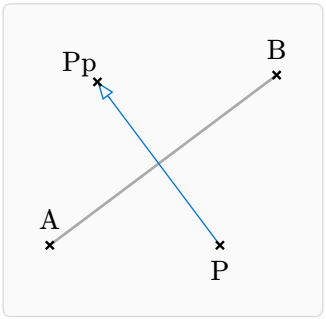
7.2. Reflection — `ctz-def-reflect`

Reflect a point across a line:

Code

```
#ctz-canvas(length: 0.75cm, {
  import cetz.draw: *
  ctz-init()

  ctz-def-points(A: (0, 0), B: (4, 3), P: (3, 0))
  ctz-def-reflect("Pp", "P", "A", "B")

  ctz-draw(segment: ("A", "B"), stroke: gray)
  ctz-draw(path: "P--Pp", stroke: blue + 0.5pt, mark:
(end: ">"), points: false, labels: false)

  ctz-draw(points: ("A", "B", "P", "Pp"), labels: (
    P: "below",
    Pp: "above left"
  ))
})
```

Figure



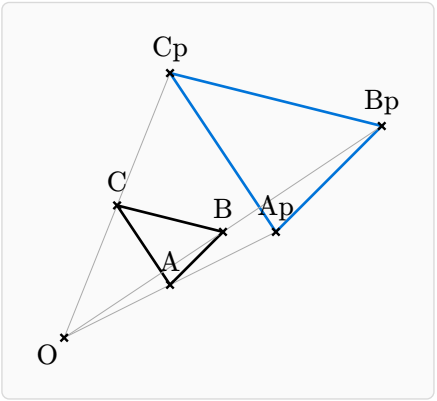
7.3. Homothety (Scaling) — `scale`

Scale a point from a center:

Code

```
#ctz-canvas(length: 0.7cm, {
  import cetz.draw: *
  ctz-init()

  ctz-def-points(O: (0, 0), A: (2, 1), B: (3, 2), C:
(1, 2.5))
  ctz-def-homothety("Ap", "A", "O", 2)
  ctz-def-homothety("Bp", "B", "O", 2)
  ctz-def-homothety("Cp", "C", "O", 2)

  ctz-draw(line: ("A", "B", "C", "A"), stroke: black)
  ctz-draw(line: ("Ap", "Bp", "Cp", "Ap"), stroke:
blue)
  ctz-draw(segment: ("O", "Ap"), stroke: gray +
0.3pt)
  ctz-draw(segment: ("O", "Bp"), stroke: gray +
0.3pt)
  ctz-draw(segment: ("O", "Cp"), stroke: gray +
0.3pt)

  ctz-draw(points: ("O", "A", "B", "C", "Ap", "Bp",
"Cp"), labels: (
    O: "below left"
  ))
})
```

Figure



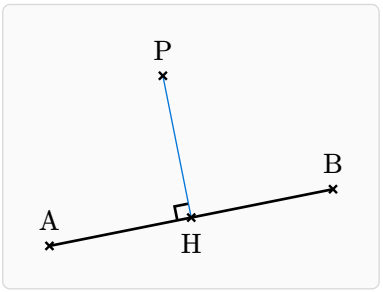
7.4. Projection — `ctz-def-project`

Project a point onto a line:

Code

```
#ctz-canvas(length: 0.75cm, {
  import cetz.draw: *
  ctz-init()

  ctz-def-points(A: (0, 0), B: (5, 1), P: (2, 3))
  ctz-def-project("H", "P", "A", "B")

  ctz-draw(segment: ("A", "B"), stroke: black)
  ctz-draw(segment: ("P", "H"), stroke: blue + 0.5pt)
  ctz-draw-mark-right-angle("A", "H", "P", size:
0.25)

  ctz-draw(points: ("A", "B", "P", "H"), labels: (
    P: "above",
    H: "below"
  ))
})
```

Figure



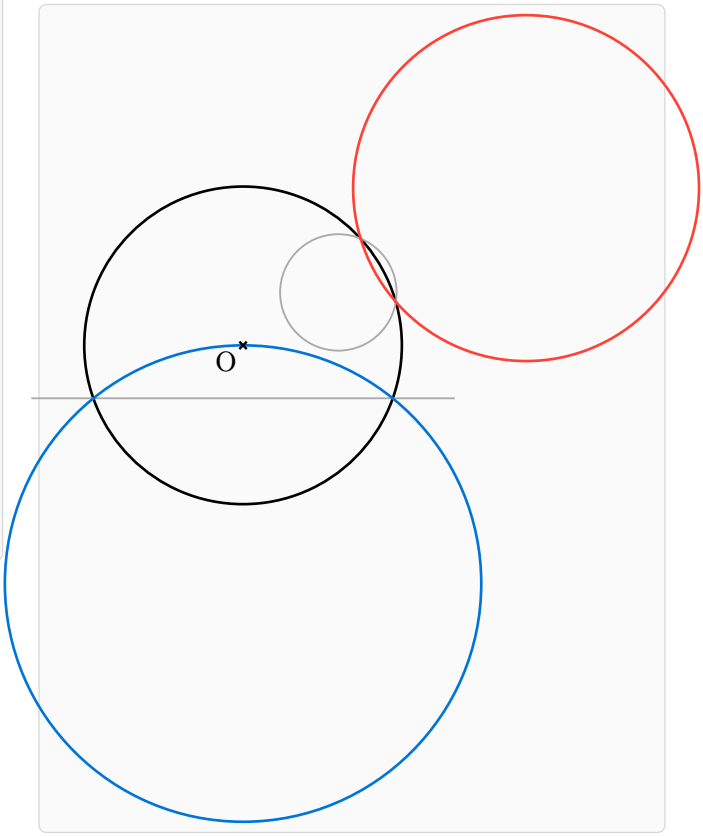
7.5. Inversion — `ctz-def-inversion`

Invert points, lines, or circles through a circle:

Code

```
#ctz-canvas(length: 0.7cm, clip-canvas: (-5, -4.5, 5,
4), {
  import cetz.draw: *
  ctz-init()

  ctz-def-points(O: (0, 0), A: (-4, -1), B: (4, -1),
C: (1.8, 1))
  ctz-def-line("L", "A", "B")
  ctz-def-circle("C1", "C", radius: 1.1)

  ctz-def-inversion("Li", "L", "O", 3)
  ctz-def-inversion("C1i", "C1", "O", 3)

  ctz-draw(circle-r: (_pt("O"), 3), stroke: black +
1pt)
  ctz-draw("L", stroke: gray + 0.7pt)
  ctz-draw("C1", stroke: gray + 0.7pt)
  ctz-draw("Li", stroke: blue + 1pt)
  ctz-draw("C1i", stroke: red + 1pt)
  ctz-draw(points: ("O"), labels: (O: "below left"))
})
```

Figure



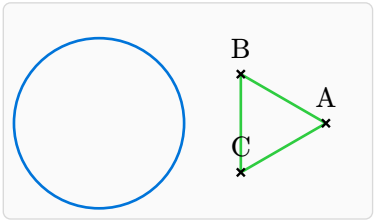
7.6. Object Duplication — `ctz-duplicate`

Duplicate any geometric object. For polygons, explicit point names must be provided.

Code

```
#ctz-canvas(length: 0.75cm, {
  import cetz.draw: *
  ctz-init()

  // Duplicate a circle
  ctz-def-circle("c1", (0, 0), radius: 1.5)
  ctz-duplicate("c2", "c1")
  ctz-draw("c1", stroke: blue)

  // Duplicate a polygon
  ctz-def-regular-polygon("tri", ("A","B","C"),
    (3, 0), (4, 0), n: 3)
  ctz-duplicate("tri2", "tri",
    points: ("A2", "B2", "C2"))
  ctz-draw("tri", stroke: green)
  ctz-draw(points: ("A", "B", "C"), labels: true)
})
```

Figure



For points, lines, and circles, duplication is straightforward. For polygons, you must provide explicit point names so the vertices can be referenced independently.

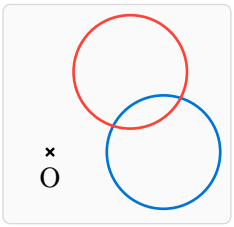
7.7. Polymorphic Rotation

The `ctz-def-rotation()` function works on all object types: points, lines, circles, and polygons.

Code

```
#ctz-canvas(length: 0.75cm, {
  import cetz.draw: *
  ctz-init()

  // Rotate a circle
  ctz-def-points(O: (0, 0))
  ctz-def-circle("c1", (2, 0), radius: 1)
  ctz-def-rotation("c2", "c1", "O", 45)

  ctz-draw("c1", stroke: blue)
  ctz-draw("c2", stroke: red)
  ctz-draw(points: ("O"), labels: (
    O: "below"
  ))
})
```

Figure



For lines, both endpoints are rotated. For circles, the center is rotated while radius remains constant. For polygons, all constituent points are rotated in place.

8. Drawing & Styling

8.1. Global Style Configuration

The package provides configurable style variables that control the default appearance of points, crosses, and marks. These are defined in `draw.typ` and can be overridden.

8.1.1. Style Variables

Variable	Default	Description
`default-point-stroke-width`	`0.9pt`	Stroke width for point markers (crosses, plus signs)
`default-mark-stroke-width`	`1pt`	Stroke width for tick marks on segments and arcs
`default-point-size`	`0.07`	Point size in canvas units (for `ctz-draw` points)
`default-point-size-pt`	`2pt`	Point size in pt (for path markers like crosses)
`default-point-size-small-pt`	`1.5pt`	Smaller point size in pt (for dots, circles, squares)
`default-point-color`	`black`	Default color for points
`default-line-color`	`black`	Default color for lines and segments
`default-mark-color`	`black`	Default color for construction marks
`default-point-shape`	`"cross"`	Default point shape (cross, dot, circle, plus, square, diamond, triangle)

8.1.2. Customizing Styles

To customize the default appearance, modify the variables in `src/draw.typ` at the top of the file:

```
// In src/draw.typ - modify these values:
#let default-point-stroke-width = 1.2pt   // thicker crosses
#let default-mark-stroke-width = 1.5pt    // thicker tick marks
#let default-point-size = 0.1             // larger points
#let default-point-size-pt = 3pt          // larger path markers
#let default-point-color = blue           // blue points
#let default-line-color = gray            // gray lines
#let default-mark-color = red             // red tick marks
#let default-point-shape = "dot"          // use dots instead of crosses
```

All drawing functions throughout the package reference these variables, so changing them once affects all drawings consistently.

The public API also exports these as `ctz-default-point-stroke-width`, `ctz-default-point-color`, etc., for inspection.

8.2. Main Levée (Hand-Drawn Style)

The package supports a "main levée" (hand-drawn/sketchy) style that adds slight perturbations to lines and shapes, giving them a natural, hand-drawn appearance.

8.2.1. Main Levée Variables

Variable	Default	Description
`default-main-levee`	`false`	Enable hand-drawn style globally
`default-main-levee-roughness`	`1.0`	Roughness amount (0 = smooth, 1-2 = typical)
`default-main-levee-seed`	`42`	Seed for reproducible randomness

8.2.2. Using Sketchy Mode with `ctz-draw`

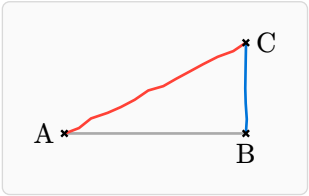
The simplest way to use hand-drawn style is to add `sketchy: true` to any `ctz-draw()` call. This works with segments, circles, polylines, ellipses, arcs, and more.

8.2.2.1. Sketchy Segments

Code

```
#ctz-canvas(length: 0.6cm, {
  import cetz.draw: *
  ctz-init()
  ctz-def-points("A", (0, 0), "B", (4, 0), "C", (4,
2))

  // Normal segment for comparison
  ctz-draw(segment: ("A", "B"), stroke: gray)

  // Sketchy segments with different roughness
  ctz-draw(segment: ("B", "C"), stroke: blue,
sketchy: true)
  ctz-draw(segment: ("C", "A"), stroke: red, sketchy:
true, roughness: 1.5)

  ctz-draw(points: ("A", "B", "C"), labels: (A:
"left", B: "below", C: "right"))
})
```

Figure



8.2.2.2. Sketchy Circles

Code

```
#ctz-canvas(length: 0.5cm, {
  import cetz.draw: *
  ctz-init()
  ctz-def-points("O", (0, 0), "P", (1.5, 0), "O2",
(5, 0), "P2", (6.5, 0))

  // Normal circle
  ctz-draw(circle-through: ("O", "P"), stroke: gray)

  // Sketchy circle
  ctz-draw(circle-through: ("O2", "P2"), stroke:
blue, sketchy: true)

  ctz-draw(points: ("O", "O2"))
})
```

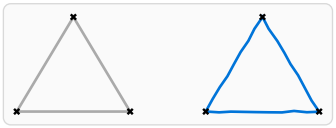
Figure

8.2.2.3. Sketchy Polylines (Triangles)

Code

```
#ctz-canvas(length: 0.5cm, {
  import cetz.draw: *
  ctz-init()
  ctz-def-points("A", (0, 0), "B", (3, 0), "C", (1.5,
2.5))
  ctz-def-points("A2", (5, 0), "B2", (8, 0), "C2",
(6.5, 2.5))

  // Normal triangle
  ctz-draw(line: ("A", "B", "C", "A"), stroke: gray)

  // Sketchy triangle
  ctz-draw(line: ("A2", "B2", "C2", "A2"), stroke:
blue, sketchy: true)

  ctz-draw(points: ("A", "B", "C", "A2", "B2", "C2"))
})
```

Figure

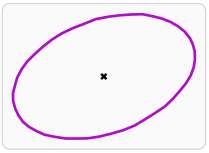


8.2.2.4. Sketchy Ellipse

Code

```
#ctz-canvas(length: 0.5cm, {
  import cetz.draw: *
  ctz-init()
  ctz-def-points("O", (0, 0))

  ctz-draw(ellipse: ("O", 2.5, 1.5, 20deg), stroke:
purple, sketchy: true)
  ctz-draw(points: ("O",))
})
```

Figure

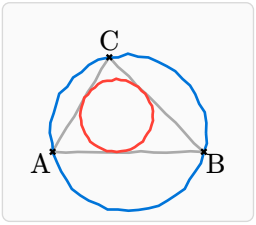


8.2.2.5. Sketchy Circumcircle and Incircle

Code

```
#ctz-canvas(length: 0.5cm, {
  import cetz.draw: *
  ctz-init()
  ctz-def-points("A", (0, 0), "B", (4, 0), "C", (1.5,
2.5))

  ctz-draw(line: ("A", "B", "C", "A"), stroke: gray,
sketchy: true)
  ctz-draw(circumcircle: ("A", "B", "C"), stroke:
blue, sketchy: true)
  ctz-draw(incircle: ("A", "B", "C"), stroke: red,
sketchy: true)

  ctz-draw(points: ("A", "B", "C"), labels: (
    A: "below left", B: "below right", C: "above"))
})
```

Figure

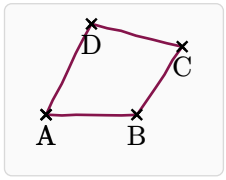


8.2.2.6. Sketchy Path

Code

```
#ctz-canvas(length: 0.6cm, {
  import cetz.draw: *
  ctz-init()
  ctz-def-points("A", (0, 0), "B", (2, 0), "C", (3,
1.5), "D", (1, 2))

  ctz-draw(path: "A--B--C--D--A", stroke: maroon,
sketchy: true, roughness: 0.8)
  ctz-draw(points: ("A", "B", "C", "D"))
})
```

Figure



8.2.3. Sketchy Parameters

The following parameters control the hand-drawn appearance:

- `sketchy: true` — Enable hand-drawn style
- `roughness: 1.0` — Controls wobbliness (0 = smooth, 1-2 = typical hand-drawn)
- `seed: 42` — Seed for reproducible randomness (same seed = same wobbles)

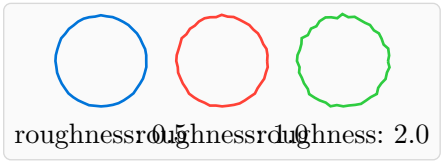
8.2.4. Roughness Comparison

The `roughness` parameter controls how "wobbly" the lines are:

Code

```
#ctz-canvas(length: 0.4cm, {
  import cetz.draw: *
  ctz-init()
  ctz-def-points("O1", (-4, 0), "P1", (-2.5, 0))
  ctz-def-points("O2", (0, 0), "P2", (1.5, 0))
  ctz-def-points("O3", (4, 0), "P3", (5.5, 0))

  // roughness = 0.5 (subtle)
  ctz-draw(circle-through: ("O1", "P1"), stroke:
blue, sketchy: true, roughness: 0.5)
  content((-4, -2.5), [roughness: 0.5])

  // roughness = 1.0 (default)
  ctz-draw(circle-through: ("O2", "P2"), stroke: red,
sketchy: true, roughness: 1.0)
  content((0, -2.5), [roughness: 1.0])

  // roughness = 2.0 (very sketchy)
  ctz-draw(circle-through: ("O3", "P3"), stroke:
green, sketchy: true, roughness: 2.0)
  content((4, -2.5), [roughness: 2.0])
})
```

Figure



8.2.5. Supported Constructs

The `sketchy: true` parameter works with:

Construct	Example
`segment:`	`ctz-draw(segment: ("A", "B"), sketchy: true)`
`line:`	`ctz-draw(line: ("A", "B", "C"), sketchy: true)`
`path:`	`ctz-draw(path: "A--B--C", sketchy: true)`
`circle-through:`	`ctz-draw(circle-through: ("O", "P"), sketchy: true)`
`circle-r:`	`ctz-draw(circle-r: ("O", 2), sketchy: true)`

`circle-diameter:`	`ctz-draw(circle-diameter: ("A", "B"), sketchy: true)`
`circumcircle:`	`ctz-draw(circumcircle: ("A", "B", "C"), sketchy: true)`
`incircle:`	`ctz-draw(incircle: ("A", "B", "C"), sketchy: true)`
`ellipse:`	`ctz-draw(ellipse: ("O", 2, 1.5), sketchy: true)`
`arc:`	`ctz-draw(arc: (center: "O", start: "A", end: "B"), sketchy: true)`
`arc-r:`	`ctz-draw(arc-r: ("O", 2, 0, 90), sketchy: true)`
`semicircle:`	`ctz-draw(semicircle: ("A", "B"), sketchy: true)`
Named objects	`ctz-draw("myCircle", sketchy: true)`

8.2.6. Low-Level Sketchy Functions

For more control, you can also use the dedicated sketchy functions directly:

```
ctz-sketchy-line((0, 0), (4, 0), stroke: blue, roughness: 1.0)
ctz-sketchy-circle((0, 0), 2, stroke: red, roughness: 1.2)
ctz-sketchy-polygon((0, 0), (3, 0), (1.5, 2.5), stroke: green)
ctz-sketchy-ellipse((0, 0), 2, 1.5, angle: 20deg, stroke: purple)
ctz-sketchy-rect((-2, -1), (2, 1), stroke: orange)
ctz-sketchy-arc((0, 0), 2, 0deg, 90deg, stroke: teal)
```

8.3. Points — `ctz-draw-points`

Draw points at named locations:

```
ctz-draw(points: ("A", "B", "C"))
```

8.4. Unified Drawing — `ctz-draw`

The `ctz-draw()` function provides a unified interface for drawing both **named objects** and **unnamed constructs**.

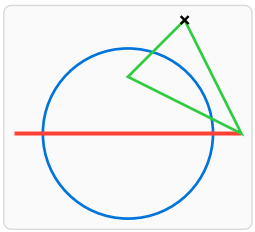
8.4.1. Drawing Named Objects

Use `ctz-draw()` to draw any object type without remembering type-specific commands. It automatically detects whether the object is a point, line, circle, polygon, or conic (ellipse/parabola/projectile).

Code

```
#ctz-canvas(length: 0.75cm, {
  import cetz.draw: *
  ctz-init()

  ctz-def-circle("c1", (0, 0), radius: 1.5)
  ctz-def-line("l1", (-2, 0), (2, 0))
  ctz-def-polygon("tri", "A", "B", "C")
  ctz-def-points(A: (1, 2), B: (2, 0), C: (0, 1))

  ctz-draw("c1", stroke: blue, fill: none)
  ctz-draw("l1", stroke: red + 1.5pt)
  ctz-draw("tri", stroke: green)
  ctz-draw("A")
})
```

Figure



8.4.2. Drawing Unnamed Constructs

You can also use `ctz-draw()` to draw geometric objects directly without defining them first using named parameters.

Define vs Draw: Most `ctz-draw()` type parameters have a corresponding `ctz-def-*` function. Use `ctz-def-*` when you need to reuse the object (for intersections, transformations, etc.). Use the draw shorthand for one-off drawing. See the summary table at the end of this section.

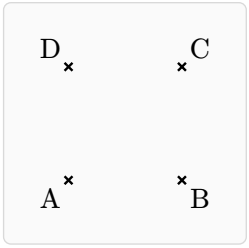
8.4.2.1. Points with Labels

Draw multiple points at once, optionally with labels:

Code

```
#ctz-canvas(length: 0.75cm, {
  import cetz.draw: *
  ctz-init()
  ctz-def-points(A: (0, 0), B: (2, 0), C: (2, 2), D:
(0, 2))

  // Draw points with custom label positions
  ctz-draw(points: ("A", "B", "C", "D"), labels: (
    A: "below left",
    B: "below right",
    C: "above right",
    D: "above left"
  ))
})
```

Figure



Use `labels: true` for default label positioning, or omit the `labels` parameter to draw points without labels.

8.4.2.2. Paths and Polylines

Draw paths using the `path:` parameter for CeTZ-style path syntax, or `line:` for polylines through points:

```
ctz-draw(path: "A--B--C--A", stroke: black)  // Close the path by repeating first point
ctz-draw(line: ("A", "B", "C", "D"), stroke: red)  // Open polyline
```

8.4.2.3. Circles

Draw circles without naming them:

```
// Circle through two points (center and point on circumference)
ctz-draw(circle-through: ("O", "A"), stroke: blue)

// Circle by center and radius
ctz-draw(circle-r: ((0, 0), 1.5), stroke: green)

// Circle by diameter endpoints
ctz-draw(circle-diameter: ("A", "B"), stroke: purple)

// Circumcircle of triangle
ctz-draw(circumcircle: ("A", "B", "C"), stroke: red)

// Incircle of triangle
ctz-draw(incircle: ("A", "B", "C"), stroke: teal)
```

8.4.2.4. Conics (Ellipses, Parabolas, Projectiles)

Draw conics without naming them:

```
// Ellipse by center, radii, and rotation angle
ctz-draw(ellipse: ((0, 0), 3, 2, 20deg), stroke: black)

// Parabola by focus + directrix (line or two points)
ctz-draw(parabola: ((0, 0), ((-2, -3), (-2, 3)), 4), stroke: black)
```

```
// Projectile by origin + velocity (optional gravity, vectors, etc.)
ctz-draw(projectile: (origin: (0, 0), velocity: (4, 6), y-floor: 0, vectors: true), stroke:
blue)
```

8.4.2.5. Arcs and Semicircles

```
// Arc by center and two points
ctz-draw(arc: (center: "O", start: "A", end: "B"), stroke: orange)

// Arc by center, radius, and angles (in degrees)
ctz-draw(arc-r: ((0, 0), 2, 0, 90), stroke: black)

// Semicircle by diameter endpoints
ctz-draw(semicircle: ("A", "B"), stroke: blue, fill: blue.lighten(80%))
```

8.4.2.6. Line Segments

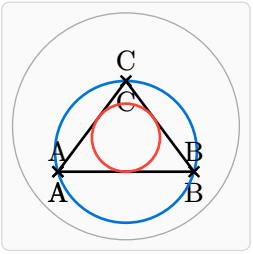
```
ctz-draw(segment: ("A", "B"), stroke: maroon + 1.5pt)
```

8.4.3. Complete Example

Code

```
#ctz-canvas(length: 0.6cm, {
  import cetz.draw: *
  ctz-init()
  ctz-def-points(A: (0, 0), B: (3, 0), C: (1.5, 2))

  // Named circle
  ctz-def-circle("myCircle", (1.5, 1), radius: 2.5)
  ctz-draw("myCircle", stroke: gray + 0.5pt)

  // Unnamed constructs
  ctz-draw(path: "A--B--C--A", stroke: black)
  ctz-draw(circumcircle: ("A", "B", "C"), stroke:
blue)
  ctz-draw(incircle: ("A", "B", "C"), stroke: red)
  ctz-draw(points: ("A", "B", "C"), labels: true)
})
```

Figure



8.5. Labels — `ctz-draw-labels`

Add labels to points with positioning:

```
ctz-draw-labels("A", "B", "C",
  A: "below left",
  B: "below right",
  C: "above")
```

Positions: `"above"`, `"below"`, `"left"`, `"right"`, `"above left"`, etc.

Custom offset:

```
ctz-draw-labels("O", O: (pos: "below", offset: (0, -0.15)))
```

More placement controls (position, offset, distance):

```
ctz-draw-labels("A", "B", "C",
  A: (pos: "above", dist: 0.25),
```

```
  B: (pos: "right", offset: (0.1, 0)),
  C: (pos: "below left", offset: (-0.05, -0.05)))
```

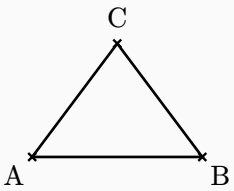
8.6. Labels & Points — Unified API (Recommended)

The modern approach combines point drawing and labeling in a single call:

Code

```
#ctz-canvas(length: 0.75cm, {
  import cetz.draw: *
  ctz-init()
  ctz-def-points(A: (0, 0), B: (3, 0), C: (1.5, 2))
  ctz-draw(line: ("A", "B", "C", "A"), stroke: black)
  ctz-draw(points: ("A", "B", "C"), labels: (
    A: "below left",
    B: "below right",
    C: "above"
  ))
})
```

Figure



This unified API replaces separate `ctz-draw-points()` and `ctz-draw-labels()` calls. The old API remains supported for backward compatibility.

You can also label points that were drawn earlier:

```
ctz-draw(points: ("A", "B"))  // Draw points without labels
// ... other drawing commands ...
ctz-draw(labels: (A: "below", B: "above"))  // Add labels later
```

8.7. Segments — `ctz-draw-segment`

Draw a segment with optional arrow or bar tips and a dimension label:

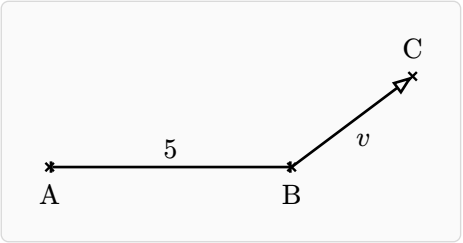
```
ctz-draw-segment("A", "B", arrows: "|-|", dim: $5$, dim-pos: "above")
```

Supported `arrows`: `--` (none), `->`, `<-`, `<->`, `|-|`, `|->`, `<-|`.

Code

```
#ctz-canvas(length: 0.8cm, {
  import cetz.draw: *
  ctz-init()

  ctz-def-points(A: (0, 0), B: (4, 0), C: (6, 1.5))

  ctz-draw-segment("A", "B", arrows: "|-|", dim: $5$,
dim-pos: "above")
  ctz-draw-segment("B", "C", arrows: "->", dim: $v$,
dim-pos: "below")
  ctz-draw(points: ("A", "B", "C"), labels: (A:
"below", B: "below", C: "above"))
})
```

Figure



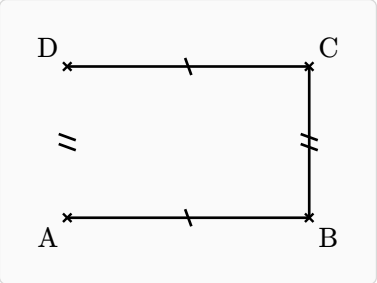
Mark equal-length segments with ticks:

```
ctz-draw-mark-segment("A", "B", mark: 1)
ctz-draw-mark-segment("C", "D", mark: 2)
```

Code

```
#ctz-canvas(length: 0.8cm, {
  import cetz.draw: *
  ctz-init()

  ctz-def-points(A: (0, 0), B: (4, 0), C: (4, 2.5),
D: (0, 2.5))
  ctz-draw(line: ("A", "B", "C", "D"), stroke: black)

  // Opposite sides equal
  ctz-draw-mark-segment("A", "B", mark: 1)
  ctz-draw-mark-segment("C", "D", mark: 1)
  ctz-draw-mark-segment("B", "C", mark: 2)
  ctz-draw-mark-segment("D", "A", mark: 2)

  ctz-draw(points: ("A", "B", "C", "D"), labels: (
    A: "below left",
    B: "below right",
    C: "above right",
    D: "above left"
  ))
})
```

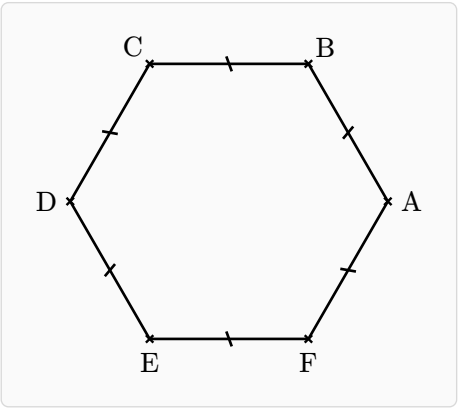
Figure



Code

```
#ctz-canvas(length: 0.7cm, {
  import cetz.draw: *
  ctz-init()

  ctz-def-points(O: (0, 0), A: (3, 0))
  ctz-def-regular-polygon("Hex", ("A", "B", "C", "D",
"E", "F"), "O", "A")

  ctz-draw-regular-polygon(("A", "B", "C", "D", "E",
"F"),
    stroke: black, mark: 1)

  // Mark all sides with the same tick
  // (use mark-opts to customize size/position)

  ctz-draw(points: ("A", "B", "C", "D", "E", "F"),
labels: (
    A: "right",
    B: "above right",
    C: "above left",
    D: "left",
    E: "below",
    F: "below"
  ))
})
```

Figure



8.8. Segment Measurements — `ctz-draw-measure-segment`

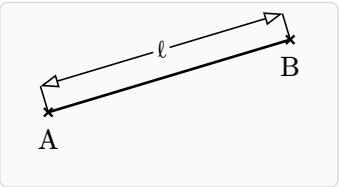
Draw an offset measurement line with dotted fences and a centered label. The line breaks around the label and uses open arrowheads by default.

```
ctz-draw-measure-segment("A", "B", label: $5$, offset: 0.3, side: "left")
```

Code

```
#ctz-canvas(length: 0.8cm, {
  import cetz.draw: *
  ctz-init()

  ctz-def-points(A: (0, 0), B: (4, 1.2))
  ctz-draw-segment("A", "B", stroke: black + 1pt)

  // Minimal measurement example
  ctz-draw-measure-segment("A", "B", label: $ell$,
offset: 0.45, side: "left",
    fence-dash: "dotted")

  ctz-draw(points: ("A", "B"), labels: (
    A: "below",
    B: "below"
  ))
})
```

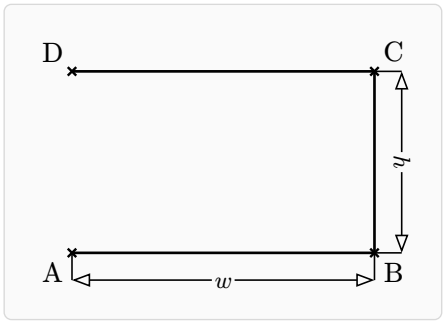
Figure



Code

```
#ctz-canvas(length: 0.8cm, {
  import cetz.draw: *
  ctz-init()

  ctz-def-points(A: (0, 0), B: (5, 0), C: (5, 3), D:
(0, 3))
  ctz-draw(line: ("A", "B", "C", "D"), stroke: black
+ 1pt)

  // Rectangle measurements (width and height)
  ctz-draw-measure-segment("A", "B", label: $w$,
offset: 0.45, side: "below")
  ctz-draw-measure-segment("C", "B", label: $h$,
offset: -0.45, side: "right")

  ctz-draw(points: ("A", "B", "C", "D"), labels: (
    A: "below left",
    B: "below right",
    C: "above right",
    D: "above left"
  ))
})
```

Figure



8.9. Paths — `ctz-draw-path`

Draw polylines with per-segment tips using a TikZ-like string:

```
ctz-draw-path("A--B->C|-|D", stroke: black)
```

Supported connectors: `--`, `->`, `<-`, `<->`, `|-|`, `|->`, `<-|`.

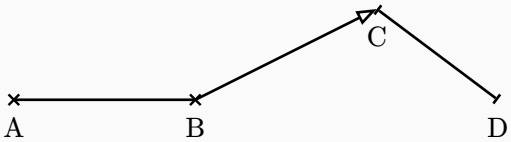
By default, `ctz-draw-path` draws points as crosses for normal segments and hides points that touch a bar connector (`|-|`, `|->`, `<-|`). Labels default to `below`. You can override per-point placements or point styles in the path with `{...}`, or via `label-overrides`.

Default behavior, label are placed below

Code

```
#ctz-canvas(length: 0.8cm, {
  import cetz.draw: *
  ctz-init()

  ctz-def-points(
    A: (0, 0), B: (3, 0), C: (6, 1.5), D: (8, 0),
  )

  // Default labels below, default point styles
  ctz-draw-path("A--B->C|-|D", stroke: black)
})
```

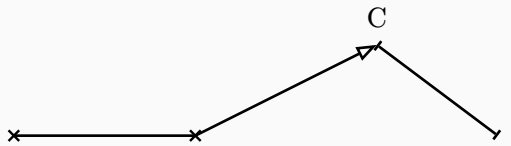
Figure



Code

```
#ctz-canvas(length: 0.8cm, {
  import cetz.draw: *
  ctz-init()

  ctz-def-points(
    A: (0, 0), B: (3, 0), C: (6, 1.5), D: (8, 0),
  )

  ctz-draw-path("A{below}--B{below}->C{above}|-|
D{below}", stroke: black)
})
```

Figure



Override placements using `label-overrides`:

```
ctz-draw-path("A--B->C|-|D",
  label-overrides: (A: "left", C: "above right"))
```

Customize point appearance or disable points/labels:

```
ctz-draw-path("A--B->C|-|D",
  point-style: "circle",
  point-color: red,
  label-pos: "above")
```

```
ctz-draw-path("A--B->C|-|D",
  points: false,
  labels: false)
```

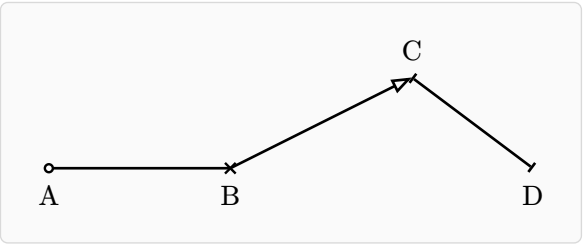
Per-point overrides inside the path:

```
ctz-draw-path("A{below, style: circle}--B{below}->C{above, style: none}|-|D{below}",
  stroke: black)
```

Code

```
#ctz-canvas(length: 0.8cm, {
  import cetz.draw: *
  ctz-init()

  ctz-def-points(
    A: (0, 0), B: (3, 0), C: (6, 1.5), D: (8, 0),
  )

  ctz-draw-path("A{below, style: circle}--B{below}-
>C{above}|-|D{below}",
    stroke: black)
})
```

Figure



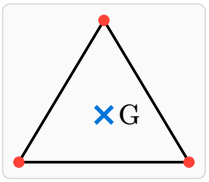
8.10. Global Styling — `ctz-style`

Set default styles for points and labels:

Code

```
#ctz-canvas(length: 0.8cm, {
  import cetz.draw: *
  ctz-init()
  ctz-style(point: (shape: "dot", size: 0.1, fill:
red))

  ctz-def-points(A: (0, 0), B: (3, 0), C: (1.5, 2.5))
  ctz-draw(line: ("A", "B", "C", "A"), stroke: black)
  ctz-draw(points: ("A", "B", "C"))

  ctz-style(point: (shape: "cross", size: 0.15,
stroke: blue + 1.5pt))
  ctz-def-centroid("G", "A", "B", "C")
  ctz-draw(points: ("G"))

  ctz-draw(points: ("G"), labels: (
    A: "below left",
    B: "below right",
    C: "above",
    G: "right"
  ))
})
```

Figure



Point shapes: `"dot"`, `"cross"`, `"circle"`, `"square"`

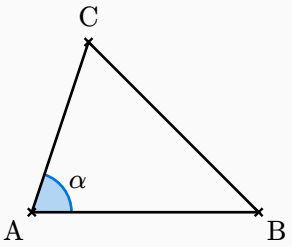
8.11. Angle Marking — `ctz-draw-angle`

Mark and label angles:

Code

```
#ctz-canvas(length: 0.8cm, {
  import cetz.draw: *
  ctz-init()

  ctz-def-points(A: (0, 0), B: (4, 0), C: (1, 3))
  ctz-draw(line: ("A", "B", "C", "A"), stroke: black)

  ctz-draw-angle("A", "B", "C",
    label: $alpha$,
    radius: 0.7,
    fill: blue.lighten(70%),
    stroke: blue)

  ctz-draw(points: ("A", "B", "C"), labels: (
    A: "below left",
    B: "below right",
    C: "above"
  ))
})
```

Figure



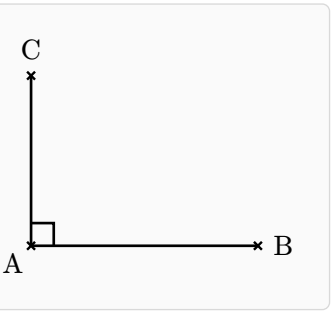
8.12. Right Angle Mark — `ctz-draw-mark-right-angle`

Mark a right angle with a small square:

Code

```
#ctz-canvas(length: 0.8cm, {
  import cetz.draw: *
  ctz-init()

  ctz-def-points(A: (0, 0), B: (4, 0), C: (0, 3))
  ctz-draw(segment: ("A", "B"), stroke: black)
  ctz-draw(segment: ("A", "C"), stroke: black)

  ctz-draw-mark-right-angle("B", "A", "C", size: 0.4)

  ctz-draw(points: ("A", "B", "C"), labels: (
    A: "below left",
    B: "right",
    C: "above"
  ))
})
```

Figure



8.13. Summary: Draw and Define Correspondence

The table below shows which `ctz-draw()` type parameters have corresponding `ctz-def-*` functions. Use `ctz-def-*` when you need to reference the object later (for intersections, transformations, etc.).

8.13.1. Geometric Objects (Have Define Functions)

Draw Shorthand	Define Function	Object Type
`points: (...)`	`ctz-def-points(...)`	Points
`line: (...)`	`ctz-def-line(name, a, b)`	Line/Polyline
`circle-r: (center, r)`	`ctz-def-circle(name, center, radius: r)`	Circle
`circle-through: (center, pt)`	`ctz-def-circle(name, center, through: pt)`	Circle
`circle-diameter: (a, b)`	`ctz-def-circle-diameter(name, a, b)`	Circle
`circumcircle: (a, b, c)`	`ctz-def-circumcircle(name, a, b, c)`	Circle
`incircle: (a, b, c)`	`ctz-def-incircle(name, a, b, c)`	Circle
—	`ctz-def-excircle(name, a, b, c, vertex: v)`	Circle
—	`ctz-def-euler-circle(name, a, b, c)`	Circle
—	`ctz-def-spieker-circle(name, a, b, c)`	Circle
—	`ctz-def-apollonius-circle(name, a, b, k)`	Circle
`ellipse: (center, rx, ry, angle)`	`ctz-def-ellipse(name, center, rx, ry, angle: 0deg)`	Conic
—	`ctz-def-ellipse-foci(n1, n2, center, rx, ry, angle)`	Points (foci)
—	`ctz-def-ellipse-tangent(name, center, rx, ry, t, ...)`	Line (tangent)
—	`ctz-def-ellipse-tangents-from(n1, n2, center, rx, ry, pt, ...)`	Lines (tangents)
`parabola: (focus, directrix, extent)`	`ctz-def-parabola(name, focus, directrix, ...)`	Conic
—	`ctz-def-parabola-focus(name, focus, p, angle, ...)`	Conic
—	`ctz-def-parabola-tangent(name, focus, directrix, t, ...)`	Line (tangent)
—	`ctz-def-parabola-tangents-from(n1, n2, focus, dir, pt, ...)`	Lines (tangents)
`projectile: (...)`	`ctz-def-projectile(name, origin, velocity, ...)`	Conic

8.13.2. Drawing Primitives (No Define Functions)

These are purely visual elements that don't need to be stored for later geometric operations:

Draw Function/Parameter	Purpose
`arc:`, `arc-r:`, `semicircle:`	Partial circles (drawing only)
`segment:`	Line segment (use `ctz-def-line` if needed)
`path:`	CeTZ-style path syntax

`labels:`	Point labels
`ctz-draw-angle`, `ctz-draw-fill-angle`	Angle arcs and fills
`ctz-draw-mark-segment`, `ctz-draw-mark-right-angle`	Geometric marks
`ctz-draw-grid`, `ctz-draw-axes`	Coordinate system decoration

9. Circles

This section covers all circle-related functions. Every circle drawing method has a corresponding define function, allowing you to store circles as named objects for later use (intersections, transformations, etc.).

9.1. Define vs Draw Pattern

For each way of creating a circle, there are two approaches:

1. **Define then Draw**: Store the circle as a named object, then draw it by name. This allows reusing the circle for intersections.
2. **Draw directly**: Use `ctz-draw()` with a type parameter to draw without storing.

```
// Approach 1: Define then draw (reusable)
ctz-def-circumcircle("C", "A", "B", "C")
ctz-draw("C", stroke: blue)
ctz-def-lc(("P", "Q"), ("A", "B"), "C")  // Can intersect with line

// Approach 2: Draw directly (one-off)
ctz-draw(circumcircle: ("A", "B", "C"), stroke: blue)
```

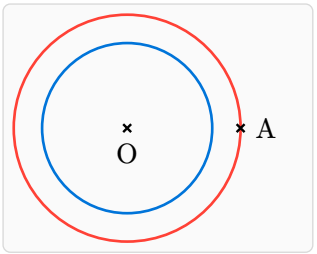
9.2. Circle by Center and Radius — `ctz-def-circle`

Define a circle by its center and either a radius value or a point on the circumference.

Code

```
#ctz-canvas(length: 0.8cm, {
  import cetz.draw: *
  ctz-init()
  ctz-def-points(O: (0, 0), A: (2, 0))

  // By radius value
  ctz-def-circle("C1", "O", radius: 1.5)
  ctz-draw("C1", stroke: blue)

  // By through point
  ctz-def-circle("C2", "O", through: "A")
  ctz-draw("C2", stroke: red)

  ctz-draw(points: ("O", "A"), labels: (O: "below",
A: "right"))
})
```

Figure



Unnamed equivalents:

```
ctz-draw(circle-r: ((0, 0), 1.5), stroke: blue)
ctz-draw(circle-through: ("O", "A"), stroke: red)
```

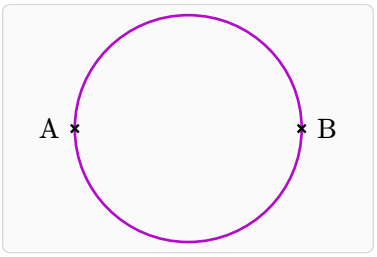
9.3. Circle by Diameter — `ctz-def-circle-diameter`

Define a circle using two points as the diameter endpoints.

Code

```
#ctz-canvas(length: 0.8cm, {
  import cetz.draw: *
  ctz-init()
  ctz-def-points(A: (-2, 0), B: (2, 0))

  ctz-def-circle-diameter("C", "A", "B")
  ctz-draw("C", stroke: purple)

  ctz-draw(points: ("A", "B"), labels: (A: "left", B:
"right"))
})
```

Figure



Unnamed equivalent:

```
ctz-draw(circle-diameter: ("A", "B"), stroke: purple)
```

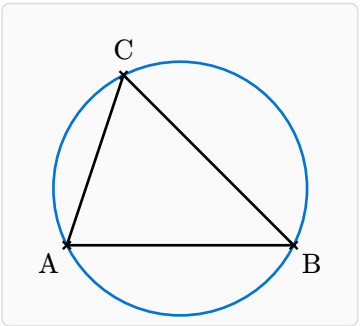
9.4. Circumcircle — `ctz-def-circumcircle`

Define the circumscribed circle of a triangle (passes through all three vertices).

Code

```
#ctz-canvas(length: 0.7cm, {
  import cetz.draw: *
  ctz-init()
  ctz-def-points(A: (0, 0), B: (4, 0), C: (1, 3))

  ctz-def-circumcircle("circ", "A", "B", "C")
  ctz-draw("circ", stroke: blue)
  ctz-draw(line: ("A", "B", "C", "A"), stroke: black)

  ctz-draw(points: ("A", "B", "C"), labels: (
    A: "below left", B: "below right", C: "above"))
})
```

Figure



Unnamed equivalent:

```
ctz-draw(circumcircle: ("A", "B", "C"), stroke: blue)
```

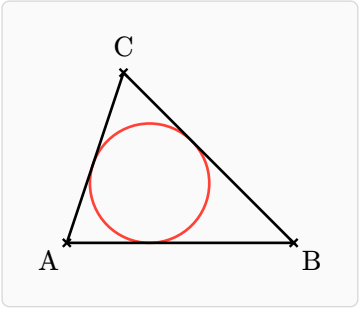
9.5. Incircle — `ctz-def-incircle`

Define the inscribed circle of a triangle (tangent to all three sides).

Code

```
#ctz-canvas(length: 0.7cm, {
  import cetz.draw: *
  ctz-init()
  ctz-def-points(A: (0, 0), B: (4, 0), C: (1, 3))

  ctz-def-incircle("inc", "A", "B", "C")
  ctz-draw("inc", stroke: red)
  ctz-draw(line: ("A", "B", "C", "A"), stroke: black)

  ctz-draw(points: ("A", "B", "C"), labels: (
    A: "below left", B: "below right", C: "above"))
})
```

Figure



Unnamed equivalent:

```
ctz-draw(incircle: ("A", "B", "C"), stroke: red)
```

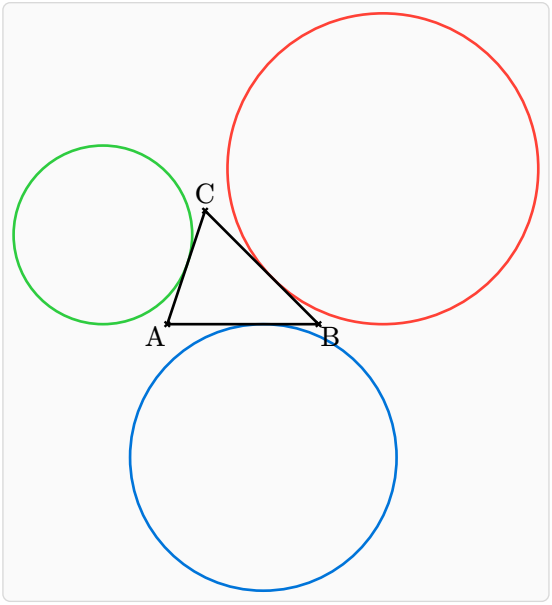
9.6. Excircle — `ctz-def-excircle`

Define an excircle of a triangle (tangent to one side and the extensions of the other two sides). The `vertex` parameter specifies which vertex the excircle is opposite to.

Code

```
#ctz-canvas(length: 0.5cm, {
  import cetz.draw: *
  ctz-init()
  ctz-def-points(A: (0, 0), B: (4, 0), C: (1, 3))

  ctz-def-excircle("excA", "A", "B", "C", vertex:
"a")
  ctz-def-excircle("excB", "A", "B", "C", vertex:
"b")
  ctz-def-excircle("excC", "A", "B", "C", vertex:
"c")

  ctz-draw("excA", stroke: red)
  ctz-draw("excB", stroke: green)
  ctz-draw("excC", stroke: blue)
  ctz-draw(line: ("A", "B", "C", "A"), stroke: black)

  ctz-draw(points: ("A", "B", "C"), labels: (
    A: "below left", B: "below right", C: "above"))
})
```

Figure



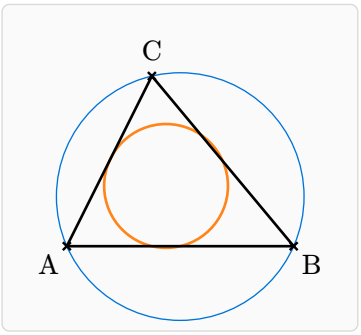
9.7. Nine-Point (Euler) Circle — `ctz-def-euler-circle`

Define the nine-point circle of a triangle. This circle passes through nine significant points: the midpoints of the three sides, the feet of the three altitudes, and the midpoints of the segments from vertices to the orthocenter.

Code

```
#ctz-canvas(length: 0.7cm, {
  import cetz.draw: *
  ctz-init()
  ctz-def-points(A: (0, 0), B: (4, 0), C: (1.5, 3))

  ctz-def-euler-circle("euler", "A", "B", "C")
  ctz-def-circumcircle("circ", "A", "B", "C")

  ctz-draw("circ", stroke: blue + 0.5pt)
  ctz-draw("euler", stroke: orange + 1pt)
  ctz-draw(line: ("A", "B", "C", "A"), stroke: black)

  ctz-draw(points: ("A", "B", "C"), labels: (
    A: "below left", B: "below right", C: "above"))
})
```

Figure



The nine-point circle has radius equal to half the circumradius.

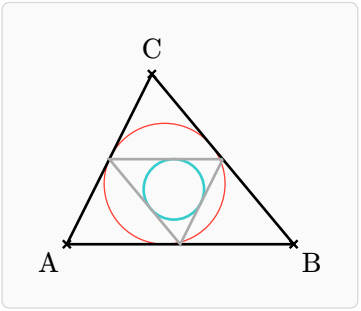
9.8. Spieker Circle — `ctz-def-spieker-circle`

Define the Spieker circle of a triangle (the incircle of the medial triangle).

Code

```
#ctz-canvas(length: 0.7cm, {
  import cetz.draw: *
  ctz-init()
  ctz-def-points(A: (0, 0), B: (4, 0), C: (1.5, 3))

  // Medial triangle
  ctz-def-medial-triangle("Ma", "Mb", "Mc", "A", "B",
"C")

  ctz-def-spieker-circle("spieker", "A", "B", "C")
  ctz-def-incircle("inc", "A", "B", "C")

  ctz-draw("inc", stroke: red + 0.5pt)
  ctz-draw("spieker", stroke: teal + 1pt)
  ctz-draw(line: ("A", "B", "C", "A"), stroke: black)
  ctz-draw(line: ("Ma", "Mb", "Mc", "Ma"), stroke:
gray)

  ctz-draw(points: ("A", "B", "C"), labels: (
    A: "below left", B: "below right", C: "above"))
})
```

Figure



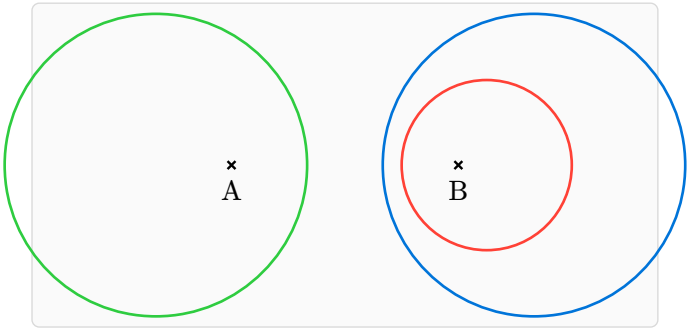
9.9. Apollonius Circle — `ctz-def-apollonius-circle`

Define an Apollonius circle — the locus of points P such that the ratio PA/PB equals a constant k.

Code

```
#ctz-canvas(length: 0.8cm, {
  import cetz.draw: *
  ctz-init()
  ctz-def-points(A: (-2, 0), B: (2, 0))

  // Circles for different ratios
  ctz-def-apollonius-circle("ap2", "A", "B", 2)
  ctz-def-apollonius-circle("ap3", "A", "B", 3)
  ctz-def-apollonius-circle("ap05", "A", "B", 0.5)

  ctz-draw("ap2", stroke: blue)
  ctz-draw("ap3", stroke: red)
  ctz-draw("ap05", stroke: green)

  ctz-draw(points: ("A", "B"), labels: (A: "below",
B: "below"))
})
```

Figure



Note: When k = 1, the locus is the perpendicular bisector of AB (a line, not a circle).

9.10. Circle Labels — `ctz-label-circle`

Place a label relative to a named circle:

```
ctz-def-circle("C1", "O", radius: 2)
ctz-draw("C1", stroke: blue)
ctz-label-circle("C1", $C_1$, pos: "above right", dist: 0.2)
```

Parameters:

- `pos`: Position around the circle (`"above"`, `"below"`, `"left"`, `"right"`, or combinations)
- `dist`: Distance from the circle edge
- `offset`: Additional (x, y) offset

9.11. Summary: Circle Functions

Define Function	Draw Shorthand	Description
`ctz-def-circle(name, center, radius: r)`	`circle-r: (center, r)`	Circle by center and radius
`ctz-def-circle(name, center, through: pt)`	`circle-through: (center, pt)`	Circle through point
`ctz-def-circle-diameter(name, a, b)`	`circle-diameter: (a, b)`	Circle by diameter
`ctz-def-circumcircle(name, a, b, c)`	`circumcircle: (a, b, c)`	Circumcircle of triangle
`ctz-def-incircle(name, a, b, c)`	`incircle: (a, b, c)`	Incircle of triangle
`ctz-def-excircle(name, a, b, c, vertex: v)`	—	Excircle opposite to vertex
`ctz-def-euler-circle(name, a, b, c)`	—	Nine-point circle
`ctz-def-spieker-circle(name, a, b, c)`	—	Spieker circle
`ctz-def-apollonius-circle(name, a, b, k)`	—	Apollonius circle (ratio k)

All defined circles can be:

- Drawn with `ctz-draw("name", stroke: ..., fill: ...)`
- Used in circle-circle intersections: `ctz-def-cc(("P", "Q"), "circle1", "circle2")`
- Used in line-circle intersections: `ctz-def-lc(("P", "Q"), line, "circle")`

10. Clipping

Lines that extend infinitely need to be clipped to the visible region.

10.1. Clip to Canvas — `ctz-canvas(clip-canvas: ...)`

You can have the canvas set the clip region automatically by providing a clip rectangle to `ctz-canvas`. This also fixes the canvas bounds to that rectangle:

```
#ctz-canvas(clip-canvas: (-1, -1, 4, 5), {
  import cetz.draw: *
  ctz-init()

  ctz-def-points(A: (0, 0), B: (2, 3))
  ctz-draw-line-add("A", "B", add: (5, 5), stroke: blue)
  ctz-show-clip(stroke: gray + 0.5pt)
})
```

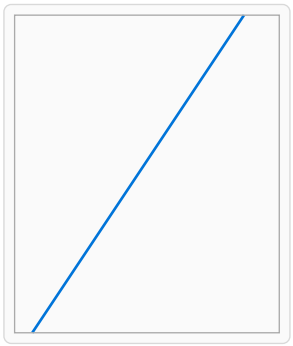
Use `clip-canvas: false` to disable this per-canvas. You can also set a global default with `ctz-default-clip-canvas`.

```
#let ctz-default-clip-canvas = (-1, -1, 4, 5)
#ctz-canvas({
  import cetz.draw: *
  ctz-init()
  // ... drawing code ...
})
```

Code

```
#ctz-canvas(length: 0.7cm, clip-canvas: (-1, -1, 4,
5), {
  import cetz.draw: *
  ctz-init()
  ctz-def-points(A: (0, 0), B: (2, 3))
  ctz-draw-line-add("A", "B", add: (5, 5), stroke:
blue)
  ctz-show-clip(stroke: gray + 0.5pt)
})
```

Figure



When `clip-canvas` is set, **only line-based elements** are clipped to the canvas bounds (extended lines and segments). Circles, arcs, and other shapes are not clipped yet. You can use the standard drawing helpers for lines:

```
ctz-draw-line-add("A", "B", add: (2, 2), stroke: blue)
ctz-draw-segment("A", "B", stroke: red)
```

11. Grid & Annotation Helpers

This section covers helper functions for creating structured diagrams with grids, highlights, and annotations. These are particularly useful for educational materials like Pascal's triangle, multiplication tables, or any grid-based visualizations.

11.1. Grid Positioning

Three grid layout systems are provided for positioning content.

11.1.1. Triangular Grid

The `triangular-pos(row, col)` function computes positions in a triangular layout where each row has one more element than the previous, centered horizontally. This is the layout used by Pascal's triangle.

Code

```
#cetz.canvas({
  import cetz.draw: *
  import "@preview/ctz-euclide:0.1.0": *
  import "@preview/ctz-euclide:0.1.0": *

  draw-triangular-grid(
    cetz.draw, 5,
    (row, col) => str(row) + "," + str(col),
    h-spacing: 1.8,
    v-spacing: 1.0,
    text-size: 9pt,
  )
})
```

Figure

Parameters:

- `row` — Row number (0 = top)
- `col` — Column within row (0 to row)
- `h-spacing` — Horizontal spacing between adjacent cells (default: 1.5)
- `v-spacing` — Vertical spacing between rows (default: 1.2)
- `origin` — Grid origin point (default: (0, 0))

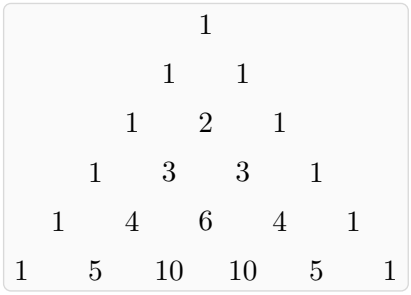
11.1.2. Pascal's Triangle

For Pascal's triangle binomial coefficients, use `draw-pascal-values`:

Code

```
#cetz.canvas({
  import cetz.draw: *
  import "@preview/ctz-euclide:0.1.0": *
  import "@preview/ctz-euclide:0.1.0": *

  draw-pascal-values(cetz.draw, 6,
    h-spacing: 1.5, v-spacing: 1.0,
    text-size: 11pt)
})
```

Figure



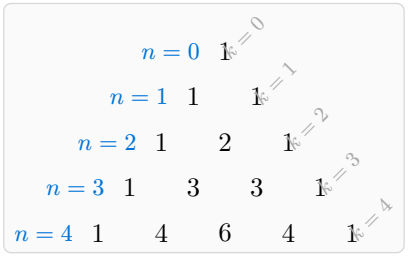
11.1.3. Row and Diagonal Labels

Add row labels (`draw-row-labels`) and diagonal labels (`draw-diagonal-labels`):

Code

```
#cetz.canvas({
  import cetz.draw: *
  import "@preview/ctz-euclide:0.1.0": *
  import "@preview/ctz-euclide:0.1.0": *

  let sp = (h: 1.4, v: 1.0)

  draw-pascal-values(cetz.draw, 5,
    h-spacing: sp.h, v-spacing: sp.v,
    text-size: 10pt)

  draw-row-labels(cetz.draw, 5,
    h-spacing: sp.h, v-spacing: sp.v,
    offset: -1.2, text-color: blue,
    format: n => $n=#n$)

  draw-diagonal-labels(cetz.draw, 5,
    h-spacing: sp.h, v-spacing: sp.v,
    offset: (0.4, 0.3), text-color: gray,
    format: k => $k=#k$)
})
```

Figure



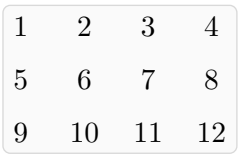
11.1.4. Rectangular Grid

The `grid-pos(row, col)` function computes positions in a standard rectangular grid:

Code

```
#cetz.canvas({
  import cetz.draw: *
  import "@preview/ctz-euclide:0.1.0": *
  import "@preview/ctz-euclide:0.1.0": *

  draw-rectangular-grid(
    cetz.draw, 3, 4,
    (r, c) => str(r * 4 + c + 1),
    h-spacing: 1.2, v-spacing: 1.0,
    text-size: 11pt)
})
```

Figure



11.1.5. Hexagonal Grid

The `hex-pos(row, col)` function computes positions in a hexagonal (honeycomb) grid:

Code

```
#cetz.canvas({
  import cetz.draw: *
  import "@preview/ctz-euclide:0.1.0": *
  import "@preview/ctz-euclide:0.1.0": hex-pos

  for row in range(3) {
    for col in range(4) {
      let p = hex-pos(row, col, size: 0.8)
      cetz.draw.circle(p, radius: 0.35,
        stroke: blue + 0.5pt,
        fill: blue.lighten(90%))
      content(p, text(size: 8pt,
        str(row) + "," + str(col)))
    }
  }
})
```

Figure

11.2. Annotation Helpers

Functions for highlighting cells and drawing annotation arrows.

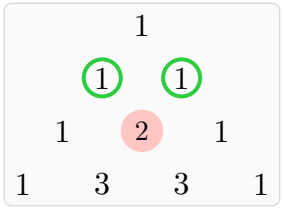
11.2.1. Cell Highlighting

`highlight-fill` draws a filled circle, `highlight-outline` draws an outlined circle, and `highlight-many` highlights multiple positions:

Code

```
#cetz.canvas({
  import cetz.draw: *
  import "@preview/ctz-euclide:0.1.0": *
  import "@preview/ctz-euclide:0.1.0": *

  draw-pascal-values(cetz.draw, 4,
    h-spacing: 1.5, v-spacing: 1.0)

  // Filled highlight
  let p1 = triangular-pos(2, 1,
    h-spacing: 1.5, v-spacing: 1.0)
  highlight-fill(cetz.draw, p1,
    radius: 0.4, fill: red.lighten(70%))
  content(p1, "2")

  // Outline highlights
  let p2 = triangular-pos(1, 0,
    h-spacing: 1.5, v-spacing: 1.0)
  let p3 = triangular-pos(1, 1,
    h-spacing: 1.5, v-spacing: 1.0)
  highlight-many(cetz.draw, (p2, p3),
    radius: 0.35, stroke: green + 1.5pt)
})
```

Figure



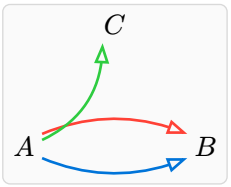
11.2.2. Curved Arrows

`curved-arrow` draws a curved annotation arrow. The `bend` parameter controls curvature direction and amount (positive = bend right, negative = bend left):

Code

```
#cetz.canvas({
  import cetz.draw: *
  import "@preview/ctz-euclide:0.1.0": *
  import "@preview/ctz-euclide:0.1.0": *

  content((0, 0), $A$)
  content((3, 0), $B$)
  content((1.5, 2), $C$)

  curved-arrow(cetz.draw,
    (0.3, 0.2), (2.7, 0.2),
    bend: 0.5, stroke: red + 1pt)

  curved-arrow(cetz.draw,
    (0.3, -0.2), (2.7, -0.2),
    bend: -0.5, stroke: blue + 1pt)

  curved-arrow(cetz.draw,
    (0.3, 0.1), (1.3, 1.7),
    bend: -0.6, stroke: green + 1pt)
})
```

Figure



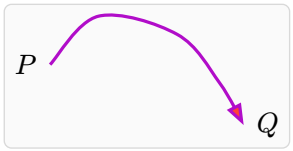
11.2.3. Smooth Arrows

`smooth-arrow` draws a Catmull-Rom spline through waypoints for complex curved paths:

Code

```
#cetz.canvas({
  import cetz.draw: *
  import "@preview/ctz-euclide:0.1.0": *
  import "@preview/ctz-euclide:0.1.0": *

  content((0, 0), $P$)
  content((4, -1), $Q$)

  smooth-arrow(cetz.draw,
    (0.4, 0), (3.6, -1),
    waypoints: (
      (1.2, 0.8),
      (2.5, 0.5),
      (3.2, -0.3),
    ),
    stroke: purple + 1.2pt)
})
```

Figure



11.2.4. Addition Indicator

`draw-addition-indicator` shows two values combining into a result (useful for Pascal's triangle):

Code

```
#cetz.canvas({
  import cetz.draw: *
  import "@preview/ctz-euclide:0.1.0": *
  import "@preview/ctz-euclide:0.1.0": *

  let a = (0, 0)
  let b = (1.5, 0)
  let sum = (0.75, -1.2)

  content(a, $3$)
  content(b, $3$)
  content(sum, $6$)

  draw-addition-indicator(cetz.draw,
    a, b, sum, color: green)
})
```

Figure

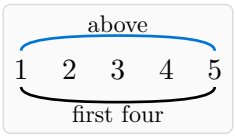
11.2.5. Braces

`draw-brace-h` and `draw-brace-v` draw horizontal and vertical braces with optional labels:

Code

```
#cetz.canvas({
  import cetz.draw: *
  import "@preview/ctz-euclide:0.1.0": *
  import "@preview/ctz-euclide:0.1.0": *

  for i in range(5) {
    content((i * 0.8, 0),
      text(size: 11pt, str(i + 1)))
  }

  draw-brace-h(cetz.draw,
    (0, -0.3), (3.2, -0.3),
    label: text(size: 9pt, "first four"),
    side: "below", amplitude: 0.25)

  draw-brace-h(cetz.draw,
    (0, 0.3), (3.2, 0.3),
    label: text(size: 9pt, "above"),
    side: "above", amplitude: 0.25,
    stroke: blue + 1pt)
})
```

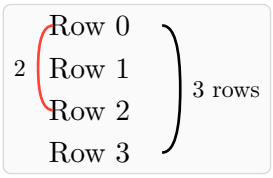
Figure



Code

```
#cetz.canvas({
  import cetz.draw: *
  import "@preview/ctz-euclide:0.1.0": *
  import "@preview/ctz-euclide:0.1.0": *

  for i in range(4) {
    content((0, -i * 0.7),
      text(size: 11pt, "Row " + str(i)))
  }

  draw-brace-v(cetz.draw,
    (1.2, 0), (1.2, -2.1),
    label: text(size: 9pt, "3 rows"),
    side: "right", amplitude: 0.3)

  draw-brace-v(cetz.draw,
    (-0.6, 0), (-0.6, -1.4),
    label: text(size: 9pt, "2"),
    side: "left", amplitude: 0.25,
    stroke: red + 1pt)
})
```

Figure



12. Raw Algorithms

For direct computation without the point registry, use the `raw` dictionary:

```
// Direct centroid calculation
let center = raw.ctz-def-centroid((0,0,0), (3,0,0), (1.5,2.5,0))

// Distance between points
let d = raw.dist((0,0,0), (3,4,0))  // Returns 5

// Line-line intersection
let pt = raw.line-line((0,0,0), (1,1,0), (0,1,0), (1,0,0), ray: true)
```

Available raw functions:

- **Intersections**: `line-line`, `line-circle`, `circle-circle`
- **Triangle centers**: `ctz-def-centroid`, `ctz-def-circumcenter`, `ctz-def-incenter`, `ctz-def-orthocenter`, `euler-center`, `ctz-def-lemoine`, etc.
- **Transformations**: `ctz-def-rotation`, `reflection`, `translation`, `ctz-def-homothety`, `projection`, `ctz-def-inversion`
- **Utilities**: `ctz-def-midpoint`, `dist`, `angle-at-vertex`, `triangle-area`, etc.

13. Function Reference

13.1. Point Definition

- `ctz-def-points(A: (x, y), ...)` — Define named points
- `ctz-def-line(name, a, b)` — Named line from two points
- `ctz-def-circle(name, center, radius|through)` — Named circle
- `ctz-def-polygon(name, a, b, c, ...)` — Named polygon
- `ctz-def-midpoint(name, a, b)` — Midpoint of segment
- `ctz-def-linear(name, a, b, k)` — Point at ratio k along line
- `ctz-def-regular-polygon([name,] names, center, first)` — Regular n-gon vertices (optionally register polygon name)
- `ctz-def-point-on-circle(name, center, radius, angle)` — Point on circle at angle
- `ctz-def-equilateral(name, a, b)` — Third vertex of equilateral triangle
- `ctz-def-golden(name, a, b)` — Golden ratio point

13.2. Line Constructions

- `ctz-def-perp(n1, n2, line, through)` — Perpendicular through point
- `ctz-def-para(n1, n2, line, through)` — Parallel through point
- `ctz-def-bisect(n1, n2, a, vertex, c)` — Angle bisector
- `ctz-def-mediator(n1, n2, a, b)` — Perpendicular bisector

13.3. Intersections

- `ctz-def-ll(name, line1, line2)` — Line-line intersection
- `ctz-def-lc(names, line, circle)` — Line-circle intersections
- `ctz-def-cc(names, circle1, circle2)` — Circle-circle intersections

13.4. Triangle Centers

- `ctz-def-centroid`, `ctz-def-circumcenter`, `ctz-def-incenter`, `ctz-def-orthocenter`
- `ctz-def-euler`, `ctz-def-lemoine`, `ctz-def-nagel`, `ctz-def-gergonne`, `ctz-def-spieker`
- `ctz-def-feuerbach`, `ctz-def-mittenpunkt`, `ctz-def-excenter`

13.5. Special Triangles

- `ctz-def-medial-triangle(na, nb, nc, a, b, c)` — Medial triangle
- `ctz-def-orthic-triangle(na, nb, nc, a, b, c)` — Orthic triangle
- `ctz-def-intouch-triangle(na, nb, nc, a, b, c)` — Intouch triangle
- `ctz-def-thales-triangle(na, nb, nc, center, radius, ...)` — Right triangle via Thales' theorem

13.6. Transformations

- `ctz-def-rotation(name, source, center, angle)` — Rotation (works on all object types)
- `ctz-def-reflect(name, source, line-a, line-b)` — Reflection
- `ctz-def-translate(name, source, vector)` — Translation
- `ctz-def-homothety(name, source, center, factor)` — Homothety
- `ctz-def-project(name, source, line-a, line-b)` — Projection
- `ctz-def-inversion(name, source, center, radius)` — Inversion (works on points, lines, circles, polygons)
- `ctz-duplicate(target, source, points: auto)` — Duplicate any geometric object

13.7. Drawing

- `ctz-draw(name, ...)` or `ctz-draw(points: ..., labels: ...)` — Draw any object type (polymorphic) or draw/label points using unified API
- `ctz-draw-points(names...)` — Draw points (legacy, prefer unified `ctz-draw()`)
- `ctz-draw-labels(names, placements)` — Label points (legacy, prefer unified `ctz-draw()`)
- `ctz-style(point: (...))` — Set styling
- `ctz-draw-angle(vertex, a, b, ...)` — Mark angle

- `ctz-draw-mark-right-angle(a, vertex, c, ...)` — Right angle mark
- `ctz-draw-segment(a, b, ...)` — Draw segment
- `ctz-draw-measure-segment(a, b, ...)` — Offset measurement with fences and label
- `ctz-draw-path(spec, ...)` — Draw path with per-segment tips
- `ctz-draw-polygon(points...)` — Draw polygon (triangle, quadrilateral, etc.)
- `ctz-draw-fill-polygon(points...)` — Fill polygon
- `ctz-draw-regular-polygon(names, ...)` — Draw regular polygon by vertex names
- `ctz-draw-fill-regular-polygon(names, ...)` — Fill regular polygon by vertex names
- `ctz-draw-circle(name, ...)` — Draw named circle
- `ctz-label-circle(name, label, ...)` — Label named circle
- `ctz-label-polygon(name, label, ...)` — Label named polygon
- `ctz-draw-circumcircle(a, b, c, ...)` — Circumscribed circle
- `ctz-draw-incircle(a, b, c, ...)` — Inscribed circle

13.8. Clipping

- `ctz-canvas(clip-canvas: ...)` — Set clip bounds for the canvas
- `ctz-show-clip(...)` — Draw the clip boundary
- `ctz-draw-line-add(a, b, ...)` — Extended line (respects clip bounds)
- `ctz-draw-segment(a, b, ...)` — Segment (respects clip bounds)

13.9. Grid Positioning

- `triangular-pos(row, col, ...)` — Position in triangular grid (Pascal layout)
- `grid-pos(row, col, ...)` — Position in rectangular grid
- `hex-pos(row, col, ...)` — Position in hexagonal grid
- `binomial(n, k)` — Binomial coefficient C(n,k)

13.10. Grid Drawing

- `draw-triangular-grid(cetz-draw, rows, content-fn, ...)` — Draw triangular grid with custom content
- `draw-rectangular-grid(cetz-draw, rows, cols, content-fn, ...)` — Draw rectangular grid
- `draw-pascal-values(cetz-draw, rows, ...)` — Draw Pascal's triangle values
- `draw-row-labels(cetz-draw, rows, ...)` — Draw row labels
- `draw-diagonal-labels(cetz-draw, count, ...)` — Draw diagonal labels

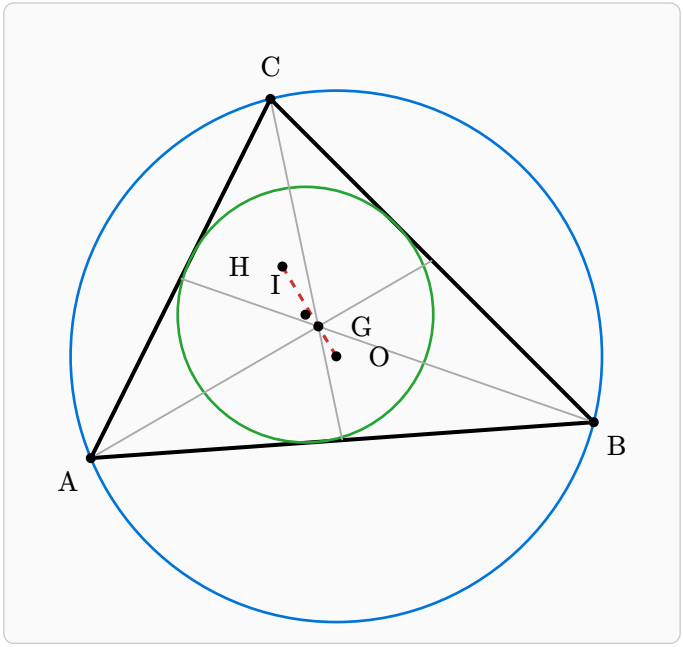
13.11. Annotations

- `highlight-fill(cetz-draw, pos, ...)` — Filled circle highlight
- `highlight-outline(cetz-draw, pos, ...)` — Outlined circle highlight
- `highlight-many(cetz-draw, positions, ...)` — Highlight multiple positions
- `curved-arrow(cetz-draw, from, to, ...)` — Curved annotation arrow
- `smooth-arrow(cetz-draw, from, to, waypoints, ...)` — Smooth spline arrow
- `draw-addition-indicator(cetz-draw, a, b, result, ...)` — Show addition relationship
- `draw-brace-h(cetz-draw, start, end, ...)` — Horizontal brace
- `draw-brace-v(cetz-draw, start, end, ...)` — Vertical brace

14. Gallery Examples

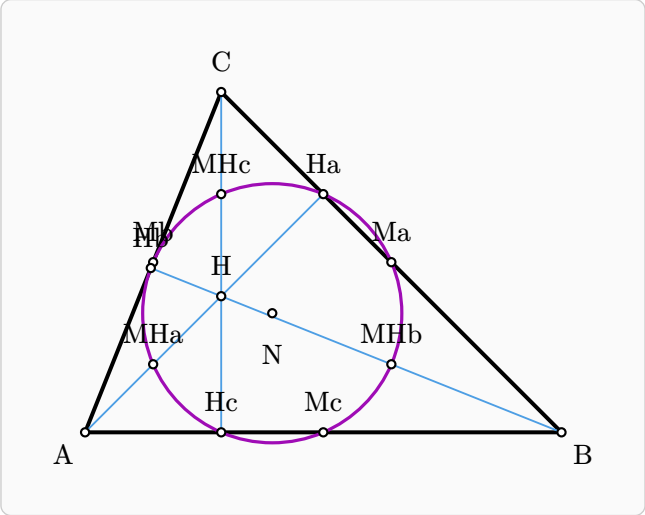
The following pages showcase advanced geometric constructions using ctz-euclide. Each example demonstrates different features and techniques.

Triangle Centers



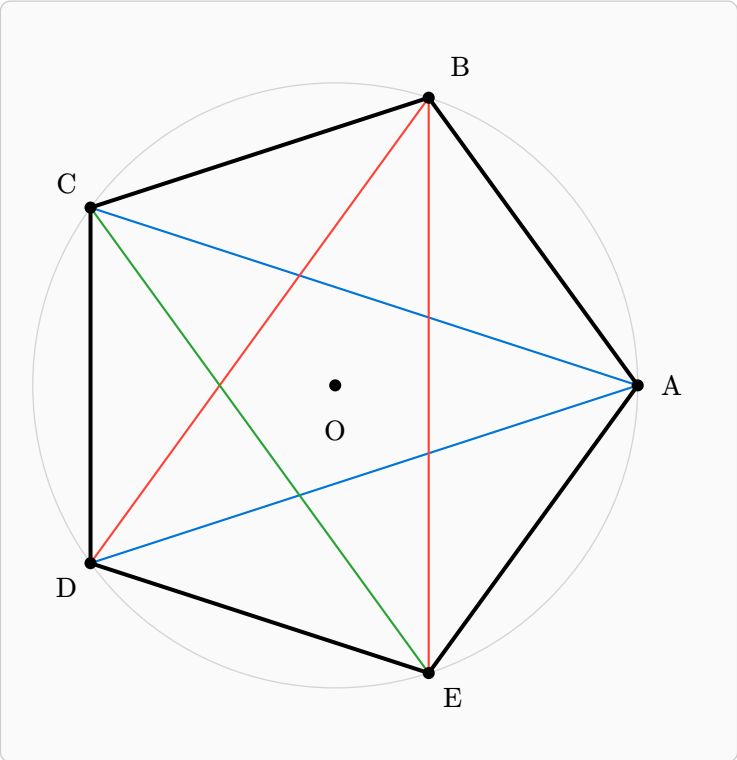

```
#ctz-canvas(length: 0.95cm, {
  import cetz.draw: *
  ctz-init()
  ctz-style(point: (shape: "dot", size: 0.07, fill: black))

  ctz-def-points(A: (0, 0), B: (7, 0.5), C: (2.5, 5))
  ctz-draw(line: ("A", "B", "C", "A"), stroke: black + 1.5pt)

  ctz-def-centroid("G", "A", "B", "C")
  ctz-def-circumcenter("O", "A", "B", "C")
  ctz-def-incenter("I", "A", "B", "C")
  ctz-def-orthocenter("H", "A", "B", "C")

  // Euler line (H, G, O are collinear)
  ctz-draw(segment: ("H", "O"), stroke: (
    paint: red.darken(20%),
    dash: "dashed",
    thickness: 1.2pt
  ))

  // Circumcircle and incircle
  ctz-draw(circle-through: ("O", "A"), stroke: blue + 1pt)
  ctz-draw(incircle: ("A", "B", "C"), stroke: green.darken(20%) + 1pt)

  // Draw medians to centroid
  ctz-def-midpoint("Ma", "B", "C")
  ctz-def-midpoint("Mb", "A", "C")
  ctz-def-midpoint("Mc", "A", "B")
  ctz-draw(segment: ("A", "Ma"), stroke: gray + 0.7pt)
  ctz-draw(segment: ("B", "Mb"), stroke: gray + 0.7pt)
  ctz-draw(segment: ("C", "Mc"), stroke: gray + 0.7pt)

  ctz-draw(points: ("A", "B", "C", "G", "O", "I", "H"), labels: (
    A: "below left",
    B: "below right",
    C: "above",
    G: "right",
    O: "below",
    I: "right",
    H: "left"
  ))
})
```

Nine-Point Circle



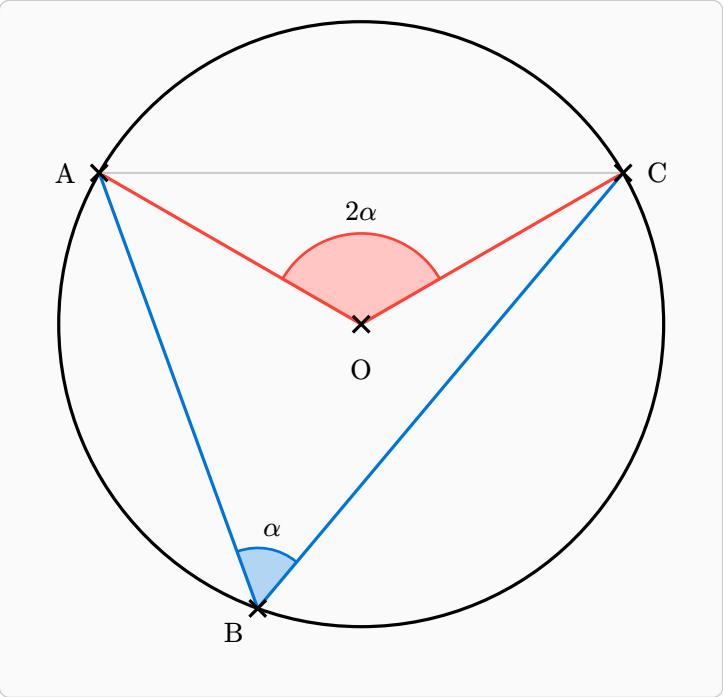

```
#ctz-canvas(length: 0.9cm, {
  import cetz.draw: *
  ctz-init()
  ctz-style(point: (shape: "circle", size: 0.06, stroke: black + 0.8pt, fill: white))

  ctz-def-points(A: (0, 0), B: (7, 0), C: (2, 5))
  ctz-draw(line: ("A", "B", "C", "A"), stroke: black + 1.5pt)

  // Midpoints of sides
  ctz-def-midpoint("Ma", "B", "C")
  ctz-def-midpoint("Mb", "A", "C")
  ctz-def-midpoint("Mc", "A", "B")

  // Feet of altitudes
  ctz-def-project("Ha", "A", "B", "C")
  ctz-def-project("Hb", "B", "A", "C")
  ctz-def-project("Hc", "C", "A", "B")

  // Orthocenter and midpoints to vertices
  ctz-def-orthocenter("H", "A", "B", "C")
  ctz-def-midpoint("MHa", "H", "A")
  ctz-def-midpoint("MHb", "H", "B")
  ctz-def-midpoint("MHc", "H", "C")

  // Nine-point circle passes through all 9 points
  ctz-def-euler("N", "A", "B", "C")
  ctz-draw(circle-through: ("N", "Ma"), stroke: purple.darken(10%) + 1.2pt)

  // Draw altitudes
  ctz-draw(segment: ("A", "Ha"), stroke: blue.lighten(30%) + 0.7pt)
  ctz-draw(segment: ("B", "Hb"), stroke: blue.lighten(30%) + 0.7pt)
  ctz-draw(segment: ("C", "Hc"), stroke: blue.lighten(30%) + 0.7pt)

  ctz-draw(points: ("A", "B", "C", "N", "Ma", "Mb", "Mc", "Ha", "Hb", "Hc", "MHa", "MHb", "MHc", "H"), labels: (
    A: "left",
    B: "right",
    C: "above",
    N: "below"
  ))
})
```

Regular Pentagon



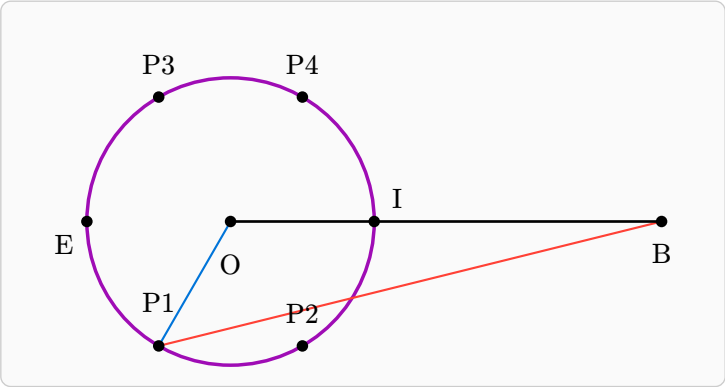

```
#ctz-canvas(length: 1cm, {
  import cetz.draw: *
  ctz-init()
  ctz-style(point: (shape: "dot", size: 0.08, fill: black))

  ctz-def-points(O: (0, 0), V1: (4, 0))
  ctz-def-regular-polygon("Pent", ("A", "B", "C", "D", "E"), "O", "V1")

  // Pentagon
  ctz-draw("Pent", stroke: black + 1.5pt)

  // All diagonals
  ctz-draw(segment: ("A", "C"), stroke: blue + 0.8pt)
  ctz-draw(segment: ("A", "D"), stroke: blue + 0.8pt)
  ctz-draw(segment: ("B", "D"), stroke: red + 0.8pt)
  ctz-draw(segment: ("B", "E"), stroke: red + 0.8pt)
  ctz-draw(segment: ("C", "E"), stroke: green.darken(20%) + 0.8pt)

  // Center
  ctz-draw(circle-r: (_pt("O"), 4), stroke: gray.lighten(50%) + 0.5pt)

  ctz-draw(points: ("A", "B", "C", "D", "E", "O"), labels: (
    A: "right",
    B: (pos: "above right", offset: (0.1, 0.1),
    C: "above left",
    D: "below left",
    E: "below right",
    O: "below"
  ))
})
```

Inscribed Angle Theorem



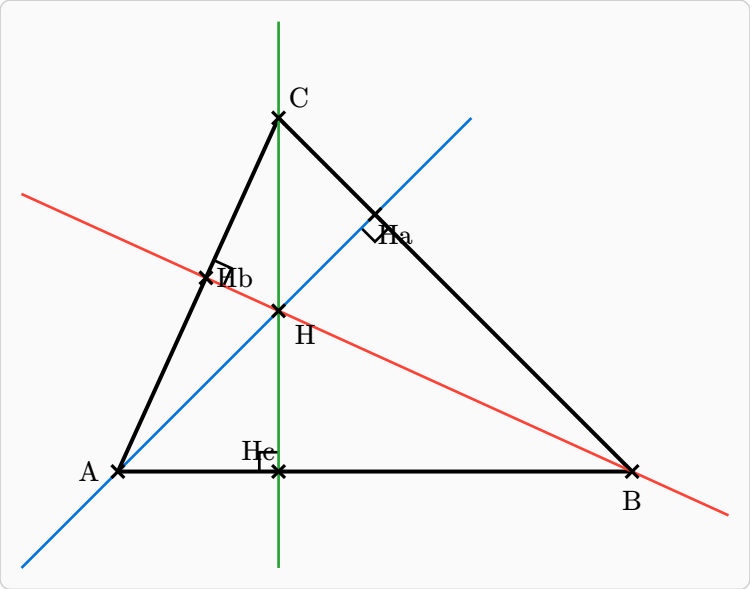

```
#ctz-canvas(length: 1cm, {
  import cetz.draw: *
  ctz-init()
  ctz-style(point: (shape: "cross", size: 0.11, stroke: black + 1.2pt))

  ctz-def-points(O: (0, 0), R: (4, 0))
  ctz-draw(circle-r: (_pt("O"), 4), stroke: black + 1.2pt)

  // Place points on circle
  ctz-def-rotation("A", "R", "O", 150)
  ctz-def-rotation("C", "R", "O", 30)
  ctz-def-rotation("B", "R", "O", 250)

  // Inscribed angle at B
  ctz-draw(segment: ("A", "B"), stroke: blue + 1.2pt)
  ctz-draw(segment: ("B", "C"), stroke: blue + 1.2pt)
  ctz-draw-angle("B", "A", "C", label: $alpha$, radius: 0.8,
    fill: blue.lighten(70%), stroke: blue)

  // Central angle at O (twice the inscribed angle)
  ctz-draw(segment: ("O", "A"), stroke: red + 1.2pt)
  ctz-draw(segment: ("O", "C"), stroke: red + 1.2pt)
  ctz-draw-angle("O", "A", "C", label: $2alpha$, radius: 1.2,
    fill: red.lighten(70%), stroke: red)

  ctz-draw(segment: ("A", "C"), stroke: gray.lighten(40%) + 0.8pt)
  ctz-draw(points: ("O", "A", "B", "C"), labels: (
    O: "below",
    A: "left",
    B: "right",
    C: "above"
  ))
})
```

Apollonius Circle



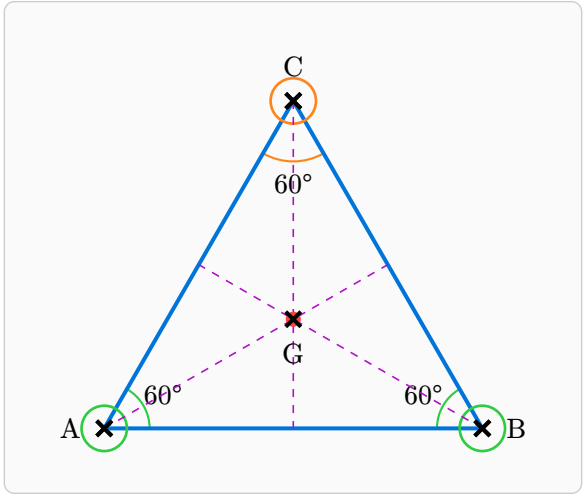

```
#ctz-canvas(length: 0.95cm, {
  import cetz.draw: *
  ctz-init()
  ctz-style(point: (shape: "dot", size: 0.08, fill: black))

  ctz-def-points(A: (-3, 0), B: (3, 0))

  // Apollonius circle: locus of points P where PA/PB = k
  let k = 2

  // External and internal division points
  ctz-def-points(E: (-5, 0), I: (-1, 0))

  // Center is midpoint of E and I
  ctz-def-midpoint("O", "E", "I")
  ctz-draw(circle-through: ("O", "E"), stroke: purple.darken(10%) + 1.3pt)

  // Show some points on the circle
  ctz-def-rotation("P1", "E", "O", 60)
  ctz-def-rotation("P2", "E", "O", 120)
  ctz-def-rotation("P3", "E", "O", -60)
  ctz-def-rotation("P4", "E", "O", -120)

  // For P1: PA/PB = k = 2
  ctz-draw(segment: ("P1", "A"), stroke: blue + 0.8pt)
  ctz-draw(segment: ("P1", "B"), stroke: red + 0.8pt)
  ctz-draw(segment: ("A", "B"), stroke: black + 1pt)

  ctz-draw(points: ( "B", "O", "E", "I", "P1", "P2", "P3", "P4"), labels: (
    B: "below right",
    E: "left",
    I: "above right",
    P1: "above",
    O: "below"
  ))
})
```

Orthocenter and Altitudes



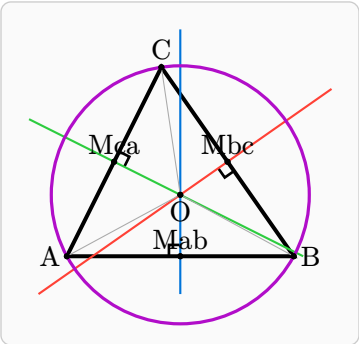

```
#ctz-canvas(length: 0.85cm, clip-canvas: (-1.5, -1.5, 9.5, 7), {
  import cetz.draw: *
  ctz-init()
  ctz-style(point: (shape: "cross", size: 0.1, stroke: black + 1.2pt))

  ctz-def-points(A: (0, 0), B: (8, 0), C: (2.5, 5.5))

  // Triangle
  ctz-draw(line: ("A", "B", "C", "A"), stroke: black + 1.5pt)

  // Extended altitudes (automatically clipped)
  ctz-def-perp("Ha1", "Ha2", ("B", "C"), "A")
  ctz-def-perp("Hb1", "Hb2", ("A", "C"), "B")
  ctz-def-perp("Hc1", "Hc2", ("A", "B"), "C")

  ctz-draw-line-add("A", "Ha1", add: (1, 1.5), stroke: blue + 1pt)
  ctz-draw-line-add("B", "Hb1", add: (1, 1.5), stroke: red + 1pt)
  ctz-draw-line-add("C", "Hc1", add: (1, 2.5), stroke: green.darken(20%) + 1pt)

  // Orthocenter (intersection of altitudes)
  ctz-def-orthocenter("H", "A", "B", "C")

  // Feet of altitudes
  ctz-def-project("Ha", "A", "B", "C")
  ctz-def-project("Hb", "B", "A", "C")
  ctz-def-project("Hc", "C", "A", "B")

  ctz-draw-mark-right-angle("A", "Ha", "B", size: 0.3)
  ctz-draw-mark-right-angle("B", "Hb", "C", size: 0.3)
  ctz-draw-mark-right-angle("C", "Hc", "A", size: 0.3)

  ctz-draw(points: ("A", "B", "C", "H", "Ha", "Hb", "Hc"), labels: (
    A: "left",
    B: "below",
    C: "above right",
    H: "right"
  ))
})
```

Equilateral Triangle Construction



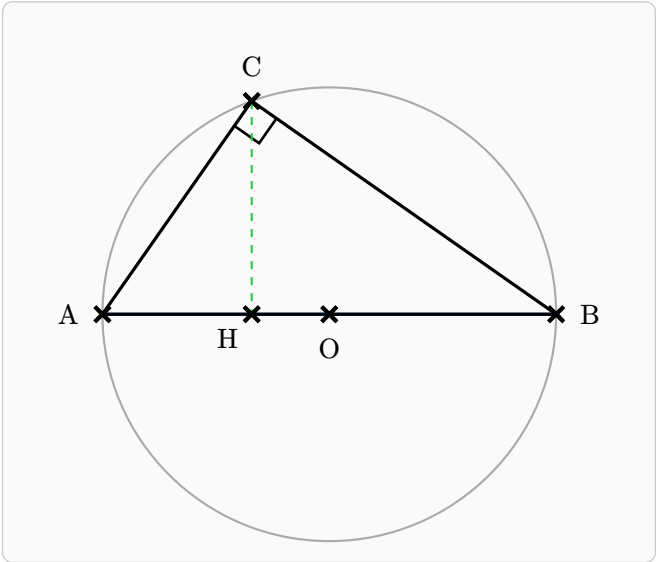

```
#ctz-canvas({
  import cetz.draw: *
  ctz-init()
  ctz-style(point: (shape: "cross", size: 0.1, stroke: black + 1.5pt))

  // Base of equilateral triangle
  ctz-def-points("A", (0, 0), "B", (5, 0))
  ctz-def-equilateral("C", "A", "B")

  // Draw triangle
  ctz-draw(line: ("A", "B", "C", "A"), stroke: blue + 1.5pt)

  // Mark 60° angles
  ctz-draw-angle("A", "B", "C", label: $60°$, radius: 0.6, stroke: green + 0.8pt)
  ctz-draw-angle("B", "C", "A", label: $60°$, radius: 0.6, stroke: green + 0.8pt)
  ctz-draw-angle("C", "A", "B", label: $60°$, radius: 0.8, stroke: orange + 0.8pt)

  // Draw circles at vertices
  ctz-draw(circle-r: (_pt("A"), 0.3), stroke: green + 1pt)
  ctz-draw(circle-r: (_pt("B"), 0.3), stroke: green + 1pt)
  ctz-draw(circle-r: (_pt("C"), 0.3), stroke: orange + 1pt)

  // In equilateral triangle, all centers coincide
  ctz-def-centroid("G", "A", "B", "C")

  // Draw medians/altitudes
  ctz-def-midpoint("Ma", "B", "C")
  ctz-def-midpoint("Mb", "A", "C")
  ctz-def-midpoint("Mc", "A", "B")
  ctz-draw(segment: ("A", "Ma"), stroke: (paint: purple, thickness: 0.6pt, dash: "dashed"))
  ctz-draw(segment: ("B", "Mb"), stroke: (paint: purple, thickness: 0.6pt, dash: "dashed"))
  ctz-draw(segment: ("C", "Mc"), stroke: (paint: purple, thickness: 0.6pt, dash: "dashed"))

  ctz-draw(points: ("A", "B", "C", "G"), labels: (
    A: "left",
    B: "right",
    C: "above",
    G: "below"
  ))
})
```

Perpendicular Bisectors and Circumcircle



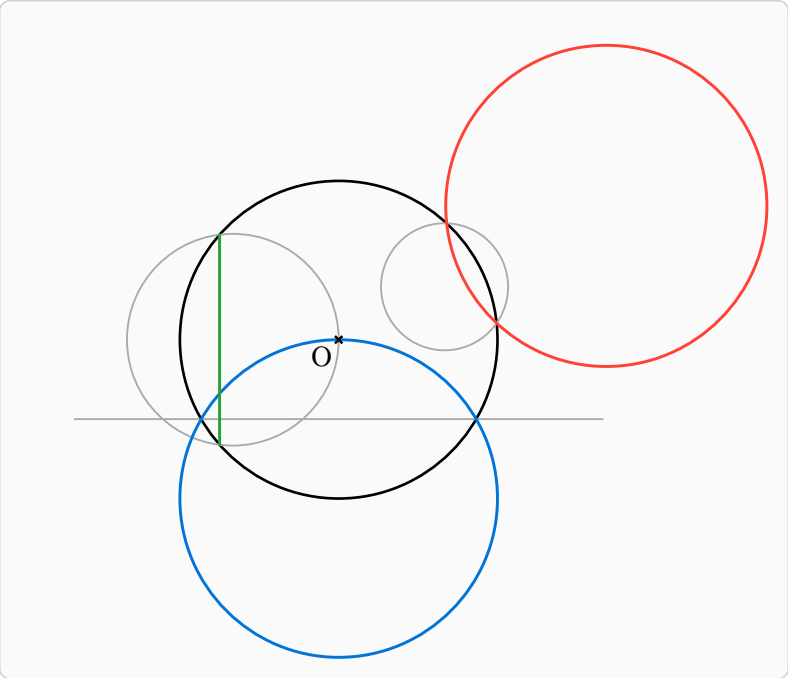

```
#ctz-canvas(clip-canvas: (-1, -1, 7, 6), {
  import cetz.draw: *
  ctz-init()
  ctz-style(point: (shape: "dot", size: 0.08, fill: black))

  // Define triangle
  ctz-def-points("A", (0, 0), "B", (6, 0), "C", (2.5, 5))

  // Calculate midpoints
  ctz-def-midpoint("Mab", "A", "B")
  ctz-def-midpoint("Mbc", "B", "C")
  ctz-def-midpoint("Mca", "C", "A")

  // Circumcenter is intersection of perpendicular bisectors
  ctz-def-circumcenter("O", "A", "B", "C")

  // Create perpendicular bisector lines
  ctz-def-mediator("Pab1", "Pab2", "A", "B")
  ctz-def-mediator("Pbc1", "Pbc2", "B", "C")
  ctz-def-mediator("Pca1", "Pca2", "C", "A")

  // Draw triangle
  ctz-draw(line: ("A", "B", "C", "A"), stroke: black + 1.5pt)

  // Draw perpendicular bisectors (clipped)
  ctz-draw-segment("Pab1", "Pab2", stroke: blue + 0.8pt)
  ctz-draw-segment("Pbc1", "Pbc2", stroke: red + 0.8pt)
  ctz-draw-segment("Pca1", "Pca2", stroke: green + 0.8pt)

  // Draw circumcircle
  ctz-draw(circumcircle: ("A", "B", "C"), stroke: purple + 1.2pt)

  // Radii (equal length)
  ctz-draw(segment: ("O", "A"), stroke: gray + 0.4pt)
  ctz-draw(segment: ("O", "B"), stroke: gray + 0.4pt)
  ctz-draw(segment: ("O", "C"), stroke: gray + 0.4pt)

  ctz-draw-mark-right-angle("A", "Mab", "O", size: 0.3)
  ctz-draw-mark-right-angle("B", "Mbc", "O", size: 0.3)
  ctz-draw-mark-right-angle("C", "Mca", "O", size: 0.3)

  ctz-draw(points: ("A", "B", "C", "O", "Mab", "Mbc", "Mca"), labels: (
    A: "left",
    B: "right",
    C: "above",
    O: "below"
  ))
})
```

Thales' Theorem




```
#ctz-canvas({
  import cetz.draw: *
  ctz-init()
  ctz-style(point: (shape: "cross", size: 0.1, stroke: black + 1.5pt))

  // Circle with diameter AB
  ctz-def-points("O", (0, 0), "A", (-3, 0), "B", (3, 0))

  // Point C on circle
  ctz-def-point-on-circle("C", "O", 3, 110)

  // Draw circle and diameter
  ctz-draw(circle-r: (_pt("O"), 3), stroke: gray + 0.8pt)
  ctz-draw(segment: ("A", "B"), stroke: blue + 1.2pt)

  // Draw triangle ACB
  // By Thales' theorem: angle ACB = 90° (inscribed in semicircle)
  ctz-draw(line: ("A", "C", "B", "A"), stroke: black + 1.2pt)

  // Mark the right angle at C
  ctz-draw-mark-right-angle("A", "C", "B", size: 0.4)

  // Draw altitude from C to AB
  ctz-def-project("H", "C", "A", "B")
  ctz-draw(segment: ("C", "H"), stroke: (paint: green, thickness: 0.8pt, dash: "dashed"))

  ctz-draw(points: ("A", "B", "C", "O", "H"), labels: (
    A: "left",
    B: "right",
    C: "above",
    O: "below",
    H: "below left"
  ))
})
```

Inversion

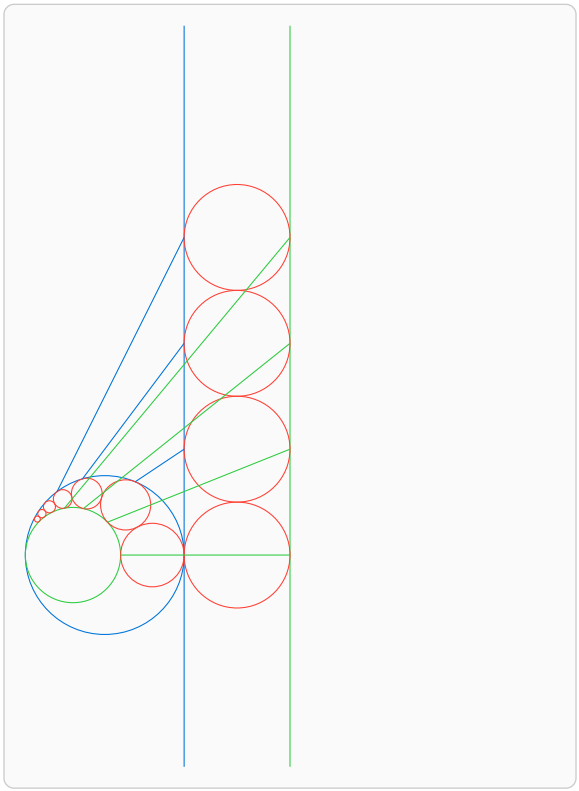



```
#ctz-canvas(clip-canvas: (-6, -5, 6, 6), {
  import cetz.draw: *
  ctz-init()

  ctz-def-points(
    O: (0, 0),
    A: (-5, -1.5),
    B: (5, -1.5),
    C: (2, 1),
    D: (-2, 0),
  )

  ctz-def-line("l1", "A", "B")
  ctz-def-circle("c1", "C", radius: 1.2)
  ctz-def-circle("c2", "D", radius: 2)

  ctz-def-inversion("l1i", "l1", "O", 3)
  ctz-def-inversion("c1i", "c1", "O", 3)
  ctz-def-inversion("c2i", "c2", "O", 3)

  ctz-draw(circle-r: (_pt("O"), 3), stroke: black + 1pt)

  ctz-draw("l1", stroke: gray + 0.7pt)
  ctz-draw("c1", stroke: gray + 0.7pt)
  ctz-draw("c2", stroke: gray + 0.7pt)

  ctz-draw("l1i", stroke: blue + 1.1pt)
  ctz-draw("c1i", stroke: red + 1.1pt)
  ctz-draw("c2i", stroke: green.darken(20%) + 1.1pt)

  ctz-draw(points: ("O"), labels: (O: "below left"))
})
```

Inversion Packing

```
#ctz-canvas({
  import cetz.draw: *
  ctz-init()

  let n = 24

  // Inversion circle setup
  ctz-def-points(O: (-4.5, 0))
  ctz-def-line("l1", (-1, 0), (-1, 1))
  ctz-def-line("l2", (1, 0), (1, 1))

  ctz-def-inversion("l1i", "l1", "O", 1)
  ctz-def-inversion("l2i", "l2", "O", 1)

  // Draw inverted lines (outer boundary)
  ctz-draw("l1i", stroke: black + 0.5pt)
  ctz-draw("l2i", stroke: black + 0.5pt)

  // Invert a stack of circles to create the packing
  for i in range(-n, n + 1) {
    let name = "c" + str(i)
    let invname = "ci" + str(i)
    ctz-def-circle(name, (0, 2 * i), radius: 1)
    ctz-def-inversion(invname, name, "O", 1)

    ctz-draw(invname, fill: yellow, stroke: red + 0.4pt)
  }
})
```

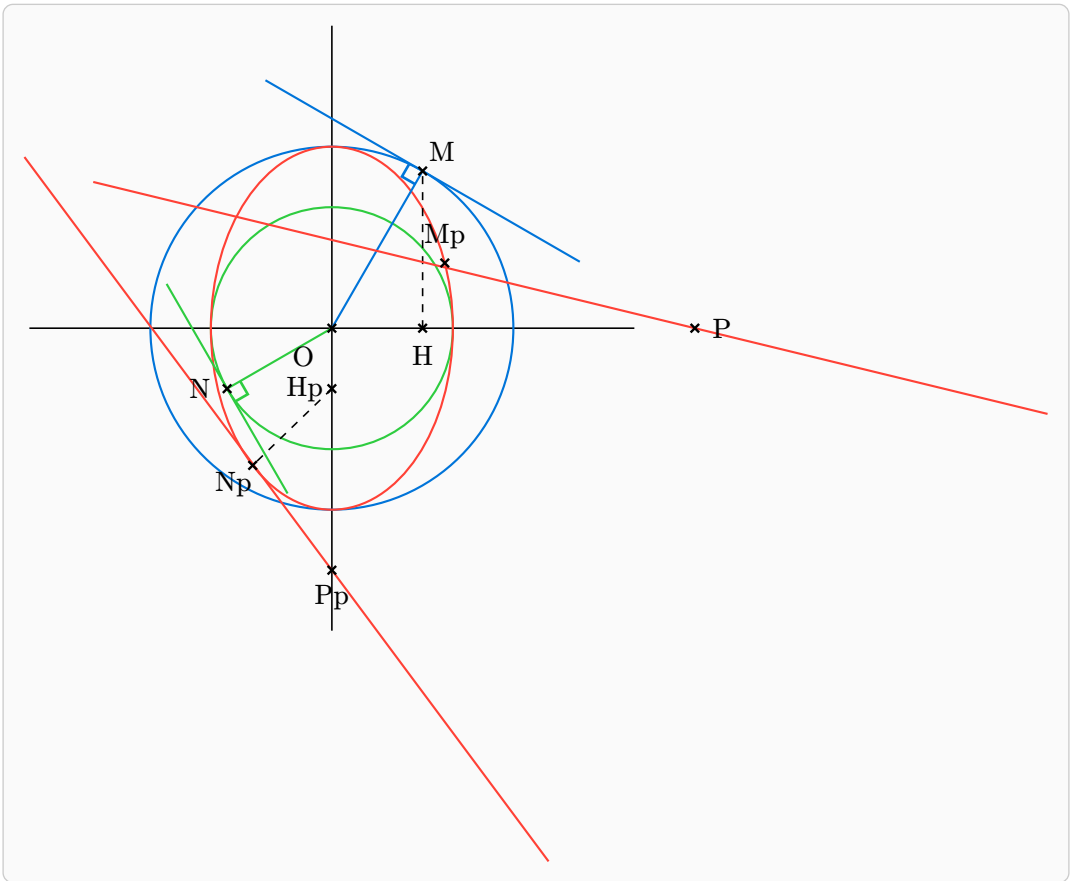
Inversion Ladder



```
#ctz-canvas(clip-canvas: (-4, -4, 6, 10), {
  import cetz.draw: *
  ctz-init()

  let O = (-4, 0)
  let R = 3
  let n = 6

  ctz-def-line("l1", (-1, 0), (-1, 1))
  ctz-def-line("l2", (1, 0), (1, 1))
  ctz-def-inversion("l1i", "l1", O, R)
  ctz-def-inversion("l2i", "l2", O, R)

  ctz-draw-line-add((-1, 0), (-1, 1), add: (10, 10), stroke: blue + 0.4pt)
  ctz-draw-line-add((1, 0), (1, 1), add: (10, 10), stroke: green + 0.4pt)
  ctz-draw("l1i", stroke: blue + 0.4pt)
  ctz-draw("l2i", stroke: green + 0.4pt)

  for i in range(0, n + 1) {
    let cname = "C" + str(i)
    let cpname = "Cp" + str(i)
    ctz-def-circle(cname, (0, 2 * i), radius: 1)
    ctz-def-inversion(cpname, cname, O, R)
    ctz-draw(cpname, stroke: red + 0.4pt)

    if calc.abs(i) < 4 {
      ctz-draw(cname, stroke: red + 0.4pt)

      ctz-def-points(P1: (1, 2 * i), P2: (-1, 2 * i))
      ctz-def-inversion("P1i", "P1", O, R)
      ctz-def-inversion("P2i", "P2", O, R)

      ctz-draw(segment: ("P1", "P1i"), stroke: green + 0.4pt)
      ctz-draw(segment: ("P2", "P2i"), stroke: blue + 0.4pt)
    }
  }
})
```

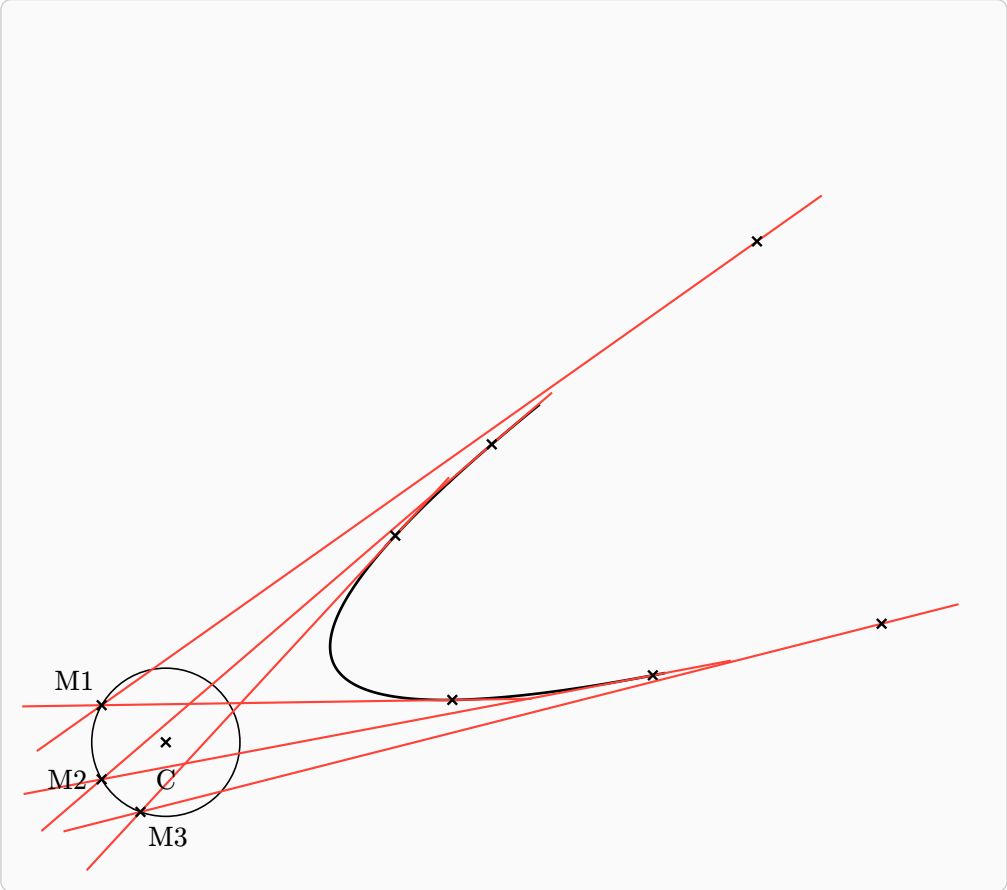
15. Advanced Examples

Ellipse and Circles Tangency



```
#ctz-canvas(length: 0.8cm, {
  import cetz.draw: *
  ctz-init()

  let a = 3
  let b = 2

  let blue-stroke = (paint: blue, thickness: 0.8pt)
  let green-stroke = (paint: green, thickness: 0.8pt)
  let red-stroke = (paint: red, thickness: 0.8pt)

  // Axes
  ctz-def-points(O: (0, 0), X1: (-5, 0), X2: (5, 0), Y1: (0, -5), Y2: (0, 5))
  ctz-draw(line: ("X1", "X2"), stroke: (paint: black, thickness: 0.6pt))
  ctz-draw(line: ("Y1", "Y2"), stroke: (paint: black, thickness: 0.6pt))

  // Circles and ellipse
  ctz-def-circle("C", "O", radius: a)
  ctz-def-circle("Cp", "O", radius: b)
  ctz-draw("C", stroke: blue-stroke)
  ctz-draw("Cp", stroke: green-stroke)
  ctz-draw(ellipse: ("O", b, a, 0deg), stroke: red-stroke)

  // Key points H, H'
  ctz-def-points(H: (a / 2, 0), Hp: (0, -b / 2))

  // Lines through H and H'
  ctz-def-perp("L1a", "L1b", ("X1", "X2"), "H")
  ctz-def-para("L2a", "L2b", ("X1", "X2"), "Hp")

  // Intersections with circles
  ctz-def-lc(("M", "M2"), ("L1a", "L1b"), "C", near: "H")
  ctz-def-lc(("N", "N2"), ("L2a", "L2b"), "Cp", near: "Hp")

  // Project M, N onto ellipse
  ctz-def-ellipse-project("Mp", "O", b, a, "M")
  ctz-def-ellipse-project("Np", "O", b, a, "N")

  // Dashed construction
  ctz-draw(line: ("H", "M"), stroke: (paint: black, thickness: 0.6pt, dash: "dashed"))
  ctz-draw(line: ("Hp", "Np"), stroke: (paint: black, thickness: 0.6pt, dash: "dashed"))

  // Radii
  ctz-draw(line: ("O", "M"), stroke: blue-stroke)
  ctz-draw(line: ("O", "N"), stroke: green-stroke)

  // Tangents at M and N
  ctz-def-tangent-at("TgM1", "TgM2", "M", "O")
  ctz-def-tangent-at("TgN1", "TgN2", "N", "O")
  ctz-draw(line: ("TgM1", "TgM2"), stroke: blue-stroke)
  ctz-draw(line: ("TgN1", "TgN2"), stroke: green-stroke)

  // Intersections with axes
  ctz-def-ll("P", ("TgM1", "TgM2"), ("X1", "X2"))
  ctz-def-ll("Pp", ("TgN1", "TgN2"), ("Y1", "Y2"))

  // Perpendicular marks
  ctz-draw-mark-right-angle("TgM1", "M", "O", color: blue)
  ctz-draw-mark-right-angle("TgN1", "N", "O", color: green)

  // Ellipse tangents from P, P'
  ctz-def-ellipse-tangent-from("Tp1", "Tp2", "O", b, a, "P", "Mp")
  ctz-def-ellipse-tangent-from("Tpp1", "Tpp2", "O", b, a, "Pp", "Np")
  ctz-draw(line: ("Tp1", "Tp2"), stroke: red-stroke, mark: (end: ">", start: ">"))
  ctz-draw(line: ("Tpp1", "Tpp2"), stroke: red-stroke, mark: (end: ">", start: ">"))

  // Labels
  ctz-draw(points: ("O", "H", "Hp", "M", "Mp", "N", "Np", "P", "Pp"), labels: (
    O: (pos: "below left", offset: (-0.15, -0.15)),
    H: "below", Hp: "left", M: "above right", Mp: "above",
    N: "left", Np: "below left", P: "right", Pp: "below"
  ))
})
```

Parabola Tangents from Circle



```
#ctz-canvas(length: 0.7cm, clip-canvas: (-4, -4, 12, 12), {
  import cetz.draw: *
  import "@preview/ctz-euclide:0.1.0": *
  ctz-init()

  let F = (0, 0)
  let p = 0.35
  let theta = 25deg

  // Draw parabola
  ctz-draw-parabola-focus(F, p, angle: theta, extent: 2.8,
    stroke: (paint: black, thickness: 1pt))

  let (D1, D2, V) = parabola-directrix-raw(F, p, angle: theta)

  // Circle positioned to be tangent to parabola
  let C = (V.at(0) + 10 * (V.at(0) - F.at(0)),
           V.at(1) + 10 * (V.at(1) - F.at(1)))
  let r = 1.4
  ctz-draw(circle-r: (C, r), stroke: (paint: black, thickness: 0.6pt))

  // Three points on circle
  let M1 = (C.at(0) + r * calc.cos(150deg), C.at(1) + r * calc.sin(150deg))
  let M2 = (C.at(0) + r * calc.cos(210deg), C.at(1) + r * calc.sin(210deg))
  let M3 = (C.at(0) + r * calc.cos(250deg), C.at(1) + r * calc.sin(250deg))

  // Draw tangent lines from each M point to parabola
  for M in (M1, M2, M3) {
    let tangents = parabola-tangents-from-point-raw(
      F, D1, D2, M, length: 1.5)
    for t in tangents {
      let (p1, p2, tp) = t
      ctz-draw(line: (p1, p2), stroke: (paint: red, thickness: 0.8pt))
      ctz-draw(points: (tp,), style: (shape: "dot", size: 2pt, fill: blue))
    }
  }

  // Label points
  ctz-def-points(C: C, M1: M1, M2: M2, M3: M3)
  ctz-draw(points: ("C", "M1", "M2", "M3"), labels: (
    C: (pos: "below", offset: (0, -0.25)),
    M1: (pos: "above left", offset: (-0.2, 0.15)),
    M2: (pos: "left", offset: (-0.2, 0)),
    M3: (pos: "below right", offset: (0.2, -0.15)),
  ))
})
```