# Parametric Curve

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## Contents



# 1 Parametric Curve

$$\int_0^1 \sqrt{\left(\frac{d\mathbf{p}}{dt}(t)\right)^2} dt \tag{1}$$

$$\tag{2}$$

# 2 Bezier Curve

$$\mathbf{p}(t) = (1-t)^3\mathbf{p}_0 + 3(1-t)^2 t\mathbf{p}_1 + 3(1-t)t^2\mathbf{p}_2 + t^3\mathbf{p}_3 \tag{3}$$

Tangent

$$\frac{d\mathbf{p}}{dt}(t) = -3(1-t)^2\mathbf{p}_0 + 3(3t-1)(t-1)\mathbf{p}_1 - 3t(3t-2)\mathbf{p}_2 + 3t^2\mathbf{p}_3 \tag{4}$$

### 2.1 De Casteljau's algorithm

# 3 B-Spline Curve

B-Spline curve is constructed from the three ingredients.

- the degree of the polynominal basis $p$.
- a set of $n$ control points $\{\mathbf{p}_0, \dots, \mathbf{p}_{n-1}\}$,
- a knot vector $\mathbf{u}$ of $m+1$ non-descending real number $\{u_0 \leq u_1 \leq u_2 \dots \leq u_m\}$ where $m = n + p$.

It is a bit confusing but, if the basis is $p$ degree polynominal, the B-Spline curve is called $p+1$ order. The order of the B-Spline means that up to $p+1$ control points affects a position of a point on the curve.

From the knot vector and $p$, we can define a basis function $N_{i,p}(u)$ which takes value in the range $u \in [u_0, u_m]$. Then, the resulting equation of the curve becomes

$$\mathbf{p}(u) = \sum_{i=0}^{n-1} N_{i,p}(u)\mathbf{p}_i \tag{5}$$

## 3.1 Knot Vector



The knot vector $\mathbf{u}$ defines segments on the parameter the curve. This allows non-uniformly sized segments and gives the B-Spline higher degree of expression. Quite frequently, the interval between knots become zero 0 if the knot takes the same value. The number of the time the knot duplicate is called *knots multiplicity*.

## 3.2 Cox - De Boor's algorithm

The basis function is defined hierarchically. In other words, we build up the basis function based on the basis function of one order lower.

We start from 0 degree basis function which is piecewise constant over the interval

$$N_{i,0}(u) = \begin{cases} 1 & if\ u_i < u < u_{i+1} \\ 0 & otherwize \end{cases} \tag{6}$$

Then, for $p > 0$, we define the basis functions using the basis function of $p-1$ degree as

$$N_{i,p}(u) = \frac{u - u_i}{u_{i+p} - u_i} N_{i,p-1}(u) + \frac{u_{i+p+1} - u}{u_{i+p+1} - u_{i+1}} N_{i+1,p-1}(u) \tag{7}$$

Figure 1 show the basis functions of the B-Spline with different degrees.

Please notice that, the degree $p$ basis function have a domain of $p + 1$ intervals. So if you go up in the higher degree, the influence of a control point gets wider, meaning that the function become smoother. Further more, given a parameter $t \in [t_0, t_m]$, it will cover by up to $p + 1$ basis function. This means that $p + 1$ control points influence a point on the B-Spline curve.

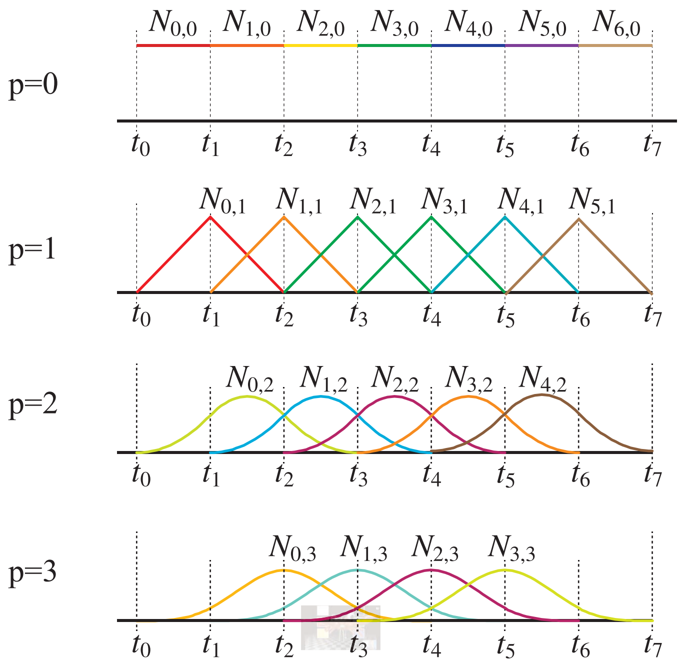



Figure 1: Basis functions of a B-Spline curve with uniform knots. The degree of the basis function increases from top row ($p = 0$) to be bottom row ($p = 3$).

Figure 2 shows that example of the B-Spline basis function construction from the basis functions of $p = 1$ to one of $p = 2$ using the (7). Starting from two neighboring basis functions we call left and right functions, we multiply a linear functions for each. For the left basis function we multiply a linear function that goes from zero to one over the domain of the function. Domain of the function means where the function takes value other than zero. In this case $p = 1$ functions takes two segments as the domain. Similarly, we multiply the right basis function to a linear function that linearly goes down from one to zero over its domain. If we multiply a linear function to $p$ degree function, we get a $p + 1$ degree function. Adding up these two functions, we get a new basis. Because the left and right basis function have domains different by one segment, the new basis function gets a one segment wider.

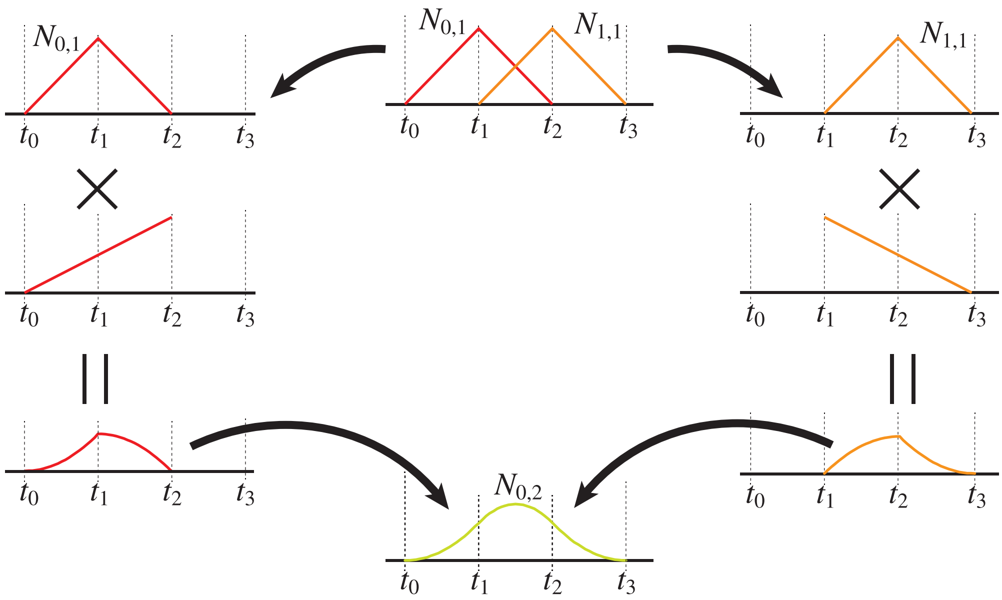



Figure 2: Cox - De Boors algorithm applied to two neighboring piece-wise linear basis functions to produce a piece-wize quadratic basis function.

### 3.3 Knot Insertion

We can insert a knot in the knot vector without changing the curve shape. Let's say we insert a knot $u$ in the knot vector. Because the knot values need to be monotonically increase, the $u$ need to be insert in the segment $[u_k, u_{k+1}]$ where $u_k \leq u \leq u_{k+1}$.

## 4 NURBS Curve

The NURBS is the abbreviation of Non-Uniform Rational B-Spline curve. "non-uniform" means that the interval of the knots can be uneven. Rational means there are weight $w$ for the control points.

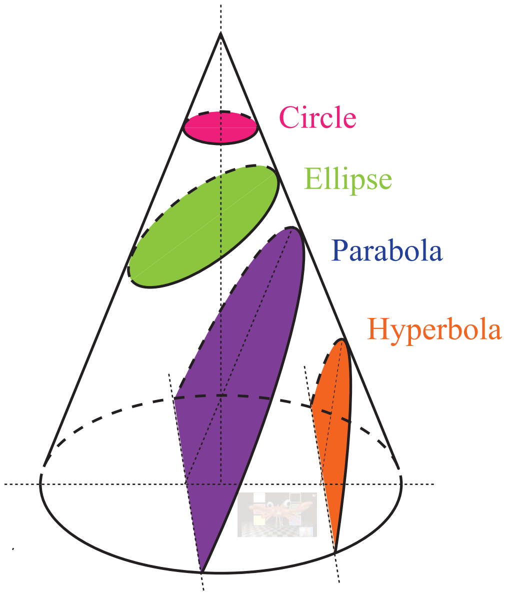
$$\mathbf{p}(u) = \frac{\sum_{i=0}^{n-1} N_{i,p}(u) w_i \mathbf{p}_i}{\sum_{i=0}^{n-1} N_{i,p} w_i} \tag{8}$$

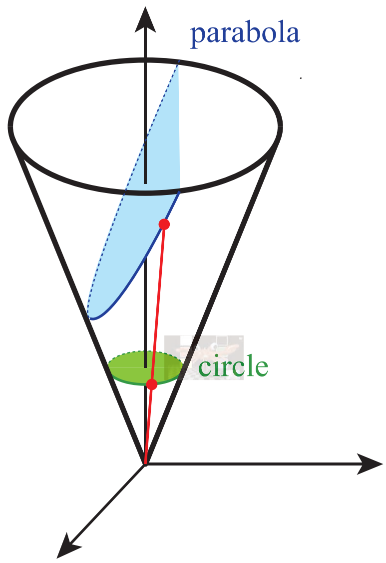
This weight gives further control ability to the curve.

Each control points have a weight $w_i$. If all the weight is 1 it becomes a B-Spline curve with non-uniform knot interval.

## 4.1 How NURBS can Represent a Perfect Circle

Let's use a homogeneous coordinate to understand how the NURBS can successfully define a perfect circle. Here we think about two dimensional space where. A homogenious coordinate has additional one dimension $w$ in addition to the $xy$. The point $(x, y, w)$ in homogeneous coordinate corresponds to the two dimensional point $(x/w, y/w)$. Such a homogeneous coordinate is called Affine transformation and is very useful in computer graphics to define perspective transformation.

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