Title

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Let $k = \bar{k}$ and R a ring containing ideals I, J.

Definition 1.0.1 (Radical)**.**
Recall that the *radical* of I is defined as

$$\sqrt{I} = \left\{ r \in R \;\middle|\; r^k \in I \text{ for some } k \in \mathbb{N} \right\}.$$

Example 1.1.
Let $I = (x_1, x_2^2) \subset \mathbb{C}[x_1, x_2]$, so $I = \left\{ f_1 x_1 + f_2 x_2 \;\middle|\; f_1, f_2 \in \mathbb{C}[x_1, x_2] \right\}$. Then $\sqrt{I} = (x_1, x_2)$, since $x_2^2 \in I \implies x_2 \in \sqrt{I}$.

Given $f \in k[x_1, \cdots, x_n]$, take its value at $a = (a_1, \cdots, a_n)$ and denote it $f(a)$. Set $\deg(f)$ to be the largest value of $i_1 + \cdots + i_n$ such that the coefficient of $\prod x_j^{i_j}$ is nonzero.

Example 1.2.
$\deg(x_1 + x_2^2 + x_1 x_2^3 = 4)$

Definition 1.0.2 (Affine Variety)**.**

1. Affine n-space $\mathbb{A}^n = \mathbb{A}_k^n$ is defined as $\left\{ (a_1, \cdots, a_n) \;\middle|\; a_i \in k \right\}$.

   Remark: not k^n, since we won't necessarily use the vector space structure (e.g. adding points).

2. Let $S \subset k[x_1, \cdots, x_n]$ to be a set of polynomials. Then define $V(S) = \left\{ x \in \mathbb{A}^n \;\middle|\; f(x) = 0 \right\} \subset \mathbb{A}^n$ to be an *affine variety*.

Example 1.3.

- $\mathbb{A}^n = V(0)$.
- For any point $(a_1, \cdots, a_n) \in \mathbb{A}^n$, then $V(x_1 - a_1, \cdots, x_n - a_n) = \{a_1, \cdots, a_n\}$ uniquely determines the point.
- For any finite set $r_1, \cdots, r_k \in \mathbb{A}^1$, there exists a polynomial $f(x)$ whose roots are r_i.

Remark 1.
We may as well assume S is an ideal by taking the ideal it generates, $S \subseteq \langle S \rangle = \left\{ \sum g_i f_i \;\middle|\; g_i \in k[x_1, \cdots, x_n],\ f_i \in S \right\}$. Then $V(\langle S \rangle) \subset V(S)$.

Conversely, if f_1, f_2 vanish at $x \in \mathbb{A}^n$, then $f_1 + f_2, gf_1$ also vanish at x for all $g \in k[x_1, \cdots, x_n]$. Thus $V(S) \subset V(\langle S \rangle)$.

Lemma 1.1.

1. If $S_1 \subseteq S_2$ then $V(S_1) \subseteq V(S_2)$.
2. $V(S_1 \bigcup S_2) = V(S_1 S_2) = V(S_1) \bigcap V(S_2)$.

We thus have a map

$$V : \{\text{Ideals in } k[x_1, \cdots, x_n]\} \longrightarrow \{\text{Affine varieties in } \mathbb{A}^n\}.$$

Definition 1.1.1 (The Ideal of a Set)**.**
Let $X \subset \mathbb{A}^n$ be any set, then *the ideal of* X is defined as

$$I(X) := \left\{ f \in k[x_1, \cdots, x_n] \;\middle|\; f(x) = 0 \,\forall x \in X \right\}.$$

Example 1.4.
Let X be the union of the x_1 and x_2 axes in $\mathbb{A}^2$, then $I(X) = (x_1 x_2) = \left\{ x_1 x_2 g \;\middle|\; g \in k[x_1, x_2] \right\}$.

Note that if $X_1 \subset X_2$ then $I(X_1) \subset I(X_2)$.

Proposition 1.2 ***(The Image of*** V ***is Radical).***
$I(X)$ is a radical ideal, i.e. $I(X) = \sqrt{I(X)}$.
This is because $f(x)^k = 0 \forall x \in X$ implies $f(x) = 0$ for all $x \in X$, so $f^k \in I(X)$ and thus $f \in I(X)$.

Our correspondence is thus

$$\left\{\text{Ideals in } k[x_1, \cdots, x_n]\right\} \xrightarrow{V} \left\{\text{Affine Varieties}\right\}$$
$$\left\{\text{Radical Ideals}\right\} \xleftarrow{I} \left\{?\right\}.$$

Proposition 1.3 ***(Hilbert Nullstellensatz (Zero Locus Theorem)).***

a. For any affine variety X, $V(I(X)) = X$.
b. For any ideal $J \subset k[x_1, \cdots, x_n]$, $I(V(J)) = \sqrt{J}$.

Thus there is a bijection between radical ideals and affine varieties.

1.1 Proof of Nullstellensatz