Finitely based 2-nilpotent Maltsev algebras

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Maltsev algebras and finite eq. bases

$\underline{A} = (A, f_1, \dots, f_n)$ ... finite algebra ($|A| < \infty$)

$\underline{A}$ is Maltsev if $\exists$ term m: $m(yxx) \approx m(xxy) \approx y$

Ex. rings $x-y+z$, groups $xy^{-1}z$, loops $(x/y)z$, BA, ...

$\boxed{\mathrm{Id}(\underline{A})}$ ... identities holding in $\underline{A}$

$\underline{A}$ is finitely based if $\exists \Sigma \subseteq \mathrm{Id}(\underline{A})$: $\boxed{|\Sigma| < \infty,\ \Sigma \models \mathrm{Id}(\underline{A})}$

Ex. $\mathbb{Z}_n$ is finitely based:

$\mathrm{Id}(\mathbb{Z}_n, +, 0, -) \dashv \{$Abelian group axioms, $n \cdot x \approx 0\}$

Finitely based Maltsev algebras

$\exists$ non-finitely based Maltsev $\underline{A}$ ($(G,\cdot,1,{}^{-1},c)$ '82 Bryant)

→ Which Maltsev algebras $\underline{A}$ are finitely based?

rewriting approach

↳ modulo some Σ every term has a normal form.

- affine $\underline{A}$ (e.g. $\mathbb{Z}_n$)
- groups (Oates, Powell '64)
- rings (L'vov/Kruse '73)
- supernilpotent $\underline{A}$ (Vaughan-Lee '83)

HSP($\underline{A}$) is residually finite

↳ non-constructive

↳ also if HSP($\underline{A}$) has difference term (KSW '16)

$\not\Downarrow$

$\xleftarrow{?}$ nilpotent $\underline{A}$

2-nilpotent Maltsev algebras

- $\underline{A}$ is affine if $Clo(\underline{A}, (a)_{a\in A}) = \{ c + \sum \alpha_i \cdot x_i \}$ w.r.t. a module
- $\underline{A}$ is 2-nilpotent $\iff \exists\, \underline{L}, \underline{U}$ affine [Freese McKenzie '87]

$\boxed{\underline{A} \simeq \underline{L} \otimes^{T} \underline{U}}$ $\quad A = L \times U, \ \forall t \in Clo(\underline{A})$:

$$t^{\underline{A}}((l_1,u_1),\dots,(l_n,u_n)) = \underbrace{(t^{\underline{L}}(\bar{l}), t^{\underline{U}}(\bar{u}))}_{\text{affine part}} + \underbrace{(\hat{t}(\bar{u}), 0)}_{\text{'distortion'}\ \hat{t}: U^n \to L}$$

In particular:

$x * y := m(x, 0, y) = x + y + \hat{t}(x_U, y_U)$ is Loop

2-nilpotent Maltsev algebras

$\underline{A}$ is 2-nilpotent $\boxed{\underline{A} \simeq \underline{L} \otimes^T \underline{U}}$

$$t^{\underline{A}}((\ell_1,u_1),\dots,(\ell_n,u_n)) = \underbrace{(t^{\underline{L}}(\bar{\ell}), t^{\underline{U}}(\bar{u}))}_{\text{affine part}} + \underbrace{(\hat{t}(\bar{u}), 0)}_{\text{‚distortion'}}$$

$\hat{t} : U^n \to L$

rewriting approach (idea)

? 1) Seperate affine and distortion part.

✓ 2) $\Sigma_{\mathrm{aff}} \models$ normal forms of affine terms

? 3) $\hat{\Sigma}$, to describe normal forms in the clonoid

$\mathrm{Clo}\,\underline{L} \circ \{ \hat{t} : U^n \to L \} \circ \mathrm{Clo}\,\underline{U}$

2-nilpotent loops of size $p \cdot q$

$p \neq q$ ... primes, $\underline{A}$ nilpotent loop $|A| = p \cdot q$

Then wlog. $\underline{A} \hat{=} \mathbb{Z}_q \otimes \mathbb{Z}_p = (\mathbb{Z}_q \times \mathbb{Z}_p, *, 0, /, \backslash)$

Lemma (→ Peter's talk)

$\underline{A}$ is term equivalent to $(\mathbb{Z}_q \times \mathbb{Z}_p, +, 0, -, \hat{r})$

$$\boxed{\begin{aligned} \hat{r}(x,y) &:= (x*y)^p / (x^p * y^p) \\ x+y &:= (x*y)/r(x,y) \end{aligned}}$$

distortion $\mathbb{Z}_p^2 \to \mathbb{Z}_q$

Abelian group

$(\mathbb{Z}_p, \mathbb{Z}_q)$ - clonoids

•) $\sum_j \lambda_j \hat{r}\left(\sum_{i=1}^{} \alpha_i x_i, \sum_{i=1}^{n} \beta_i x_i\right)$ form a $(\mathbb{Z}_p, \mathbb{Z}_q)$-clonoid $\mathcal{C}$

Theorem (Fioravanti '19) → Patrick's talk

1) $\mathcal{C}$ is generated by unaries $\mathcal{C}^{(1)} = \{\hat{f}(x) \in \mathcal{C}\} \leq \mathbb{Z}_q^{\mathbb{Z}_p}$

2) $\hat{f} \in \mathcal{C} \iff \hat{f}(\alpha_1 x, \alpha_2 x, \ldots, \alpha_n x) \in \mathcal{C}^{(1)} \quad \forall \bar{\alpha} \in \mathbb{Z}_p^n$

3) Already one $\hat{g} \in \mathcal{C}^{(1)}$ generates $\mathcal{C}$

↳ $\underline{A}$ is term equivalent to $(\mathbb{Z}_q \times \mathbb{Z}_p, +, 0, -, \hat{g})$

⇒ full classification of 2-nil. $\underline{A}$, $|A| = pq$, with constant.

$(\mathbb{Z}_p, \mathbb{Z}_q)$ - clonoids

For $\bar{a} = (0,\dots,0,1,a_i,\dots,a_n) \in \mathbb{Z}_p^n$, $f \in \mathcal{C}^{(1)}$, let $f^{\bar{a}}(\bar{x}) := \begin{cases} f(x) & \text{if } \bar{x} = (a_1 x, \dots, a_n x) \\ 0 & \text{else} \end{cases}$

Corollary (Fioravanti '19)

If B is basis of $\mathcal{C}^{(1)}$, then

$$\left.\begin{array}{l} 1)\ B_1^n = \{ f^{\bar{a}} \mid f \in B \} \\ 2)\ B_2^n = \{ f(\bar{a} \cdot \bar{x}) \mid f \in B \}. \end{array}\right\} \text{is a basis of } \mathcal{C}^{(n)} = \{ f : \mathbb{Z}_p^n \to \mathbb{Z}_q \mid f \in \mathcal{C} \}$$

Subpower membership of $\mathbf{A}$ is in P: (Peter's talk)

$$Sg_{\mathbf{A}^n}(\bar{a}_1, \dots, \bar{a}_k) = Sg_{(A_1^n,+)}(\bar{a}_1, \dots, \bar{a}_k) + Sg_{(A_1^n,+)}\big(\underbrace{B_1^n(\bar{a}_1, \dots, \bar{a}_k)}_{\text{can be computed in } |B| \cdot n}\big)$$

A finite basis

Summary $\underline{A} = (\mathbb{Z}_q \times \mathbb{Z}_p, +, 0, -, \underbrace{\hat{f}_1, \dots, \hat{f}_n}_{B \text{ basis of } C^{(1)}})$

- $t \in \mathrm{Clo}\,\underline{A}$ has a normal form

$$t(x_1, \dots, x_n) = \underbrace{\sum_i \beta_i x_i}_{\text{affine}} + \underbrace{\sum_{f \in B, \bar{\alpha}} \lambda_{f,\bar{\alpha}} f(\bar{\alpha} \cdot \bar{x})}_{\text{lin.com. over } B_2^n}$$

Rewriting using

- $+$ is Abelian group, $[pq] \cdot x \approx 0$ $\quad \Sigma_{\mathrm{aff}}$
- $q \cdot \hat{f}_i(x) \approx 0$, $\hat{f}_i(x + p \cdot y) \approx \hat{f}_i(x)$, $\hat{f}_i(x + \hat{f}_i(y)) \approx \hat{f}_i(x)$ $\quad \hat{\Sigma}$
- $\hat{f}_i(c \cdot x) \approx \sum_{f \in B} \lambda_j f_j(x)$ for all $c \in \mathbb{Z}_p$

$\Rightarrow$ $\underline{A}$ is finitely based

What I was hoping to tell you...

For general $\underline{A} = (\mathbb{Z}_q \times \mathbb{Z}_p, m(x,y,z), f_1 \dots f_n))$

rewriting approach

↯ 1) Seperate affine and distortion part

✓ 2) $\Sigma_{aff} \models$ normal forms of affine term

✓ 3) $\hat{\Sigma}$, to describe normal forms in the clonoid

$\mathcal{C} = \mathrm{Clo}(\mathbb{Z}_q, +) \circ \{\hat{t} : U \to L\} \circ \mathrm{Clo}(\mathbb{Z}_p, \underline{x-y+z})$

↳ $\mathcal{C}$ generated by $\mathcal{C}^{(2)}$

↳ $x - y + z \in \mathrm{Clo}\,\underline{A}$?

we don't know!!

→ Peter's talk ←

The clonoid part

Let $\mathcal{C}$ be a $((\mathbb{Z}_p, x-y+z), (\mathbb{Z}_q, +))$-clonoid

* s.t. $\hat{f}(x \dots x) \approx 0 \quad \forall \hat{f} \in \mathcal{C}$

Theorem (Wyme... ?)

1) $\mathcal{C}$ is generated by binary $\mathcal{C}^{(2)} \leq \mathbb{Z}_q^{\mathbb{Z}_p^2}$

2) $\hat{f} \in \mathcal{C} \iff \hat{f}(\alpha_1 x + (1-\alpha_1)y, \dots, \alpha_n x + (1-\alpha_n)y) \in \mathcal{C}^{(2)}$

2-dim subspaces $\leq \mathbb{Z}_p^n$ containing $(x x \dots x)$

If B ... basis of $\mathcal{C}^{(2)}$, then

3) $B_1^{(n)} = \{ f^{\bar{\alpha}} \mid f \in B \}$ is basis of $\mathcal{C}^{(n)}$

4) $B_2^{(n)} = \{ f(x_1, \bar{\alpha} \cdot \bar{x}) \mid f \in B \}$

Do we actually need $x-y+z$?

For $\underline{A} = (\mathbb{Z}_q \times \mathbb{Z}_p, m(xyz), f_1 \dots f_n)$

For $t, s \in \mathrm{Clo}\,\underline{A}$ define $t \sim s :\Leftrightarrow t_{aff} = s_{aff}$

$\mathcal{C} := \{ t - s \mid t \sim s \}$ is $((\mathbb{Z}_p, x-y+z), (\mathbb{Z}_q, +))$-clonoid

obs.: If $f \in \mathrm{Clo}\,\underline{A}, \hat{r} \in \mathcal{C} \Rightarrow f + \hat{r} \in \mathcal{C}$

Rewriting strategy:

~ •) Find normal forms $t = t_m + \hat{t}$, $t_m \in \mathrm{Clo}(A, m)$, $\hat{t} \in \mathcal{C}$
not affine

✓ •) Finite identities computing $\hat{t}$

~ •) Finite identities for computing t_m (e.g. $m(xyz) \approx m(zyx) + \hat{r}(xyz)$, $\hat{r} \in \mathcal{C}$)

Thank you!

Any questions?