# A tail of a generic real Classifying invariants for $E_{1}$ 

Assaf Shani

Harvard University

Advances in Set Theory HUJI, July 2022

## An intersection model

Let $x \in \mathbb{R}^{\omega}$ be Cohen generic. Define the tail intersection model

$$
M=\bigcap_{n<\omega} V\left[\left\langle x_{n}, x_{n+1}, \ldots\right\rangle\right] .
$$

## An intersection model

Let $x \in \mathbb{R}^{\omega}$ be Cohen generic. Define the tail intersection model

$$
M=\bigcap_{n<\omega} V\left[\left\langle x_{n}, x_{n+1}, \ldots\right\rangle\right] .
$$

This model was considered by Kanovei-Sabok-Zapletal (2013) and Larson-Zapletal (2020), while studying $E_{1}$.

## An intersection model

Let $x \in \mathbb{R}^{\omega}$ be Cohen generic. Define the tail intersection model

$$
M=\bigcap_{n<\omega} V\left[\left\langle x_{n}, x_{n+1}, \ldots\right\rangle\right] .
$$

This model was considered by Kanovei-Sabok-Zapletal (2013) and Larson-Zapletal (2020), while studying $E_{1}$.
$E_{1}$ is the equivalence relation on $\mathbb{R}^{\omega}$ :
$x E_{1} y \Longleftrightarrow(\exists n)(\forall m>n) x(m)=y(m)$.

## An intersection model

Let $x \in \mathbb{R}^{\omega}$ be Cohen generic. Define the tail intersection model

$$
M=\bigcap_{n<\omega} V\left[\left\langle x_{n}, x_{n+1}, \ldots\right\rangle\right] .
$$

This model was considered by Kanovei-Sabok-Zapletal (2013) and Larson-Zapletal (2020), while studying $E_{1}$.
$E_{1}$ is the equivalence relation on $\mathbb{R}^{\omega}$ :
$x E_{1} y \Longleftrightarrow(\exists n)(\forall m>n) x(m)=y(m)$.
What this model looks like was left open. In particular: does it satisfy choice?

## An intersection model

Let $x \in \mathbb{R}^{\omega}$ be Cohen generic. Define the tail intersection model

$$
M=\bigcap_{n<\omega} V\left[\left\langle x_{n}, x_{n+1}, \ldots\right\rangle\right] .
$$

This model was considered by Kanovei-Sabok-Zapletal (2013) and Larson-Zapletal (2020), while studying $E_{1}$.
$E_{1}$ is the equivalence relation on $\mathbb{R}^{\omega}$ :
$x E_{1} y \Longleftrightarrow(\exists n)(\forall m>n) x(m)=y(m)$.
What this model looks like was left open. In particular: does it satisfy choice?

We will see some structural results about this model.
The main topic of this talk is: what do the properties of this model tell us about $E_{1}$ ?

## Complete classifications

Let $E$ be an equivalence relation on $X$.
A complete classification of $E$ is a map $c: X \rightarrow I$

$$
x E y \Longleftrightarrow c(x)=c(y)
$$

## Complete classifications

Let $E$ be an equivalence relation on $X$.
A complete classification of $E$ is a map $c: X \rightarrow I$

$$
x E y \Longleftrightarrow c(x)=c(y)
$$

Some "bad" examples:


- $c: X / E \rightarrow X$ choice function $c\left([x]_{E}\right) \in[x]_{E}$. (Not definable)


## Complete classifications

Let $E$ be an equivalence relation on $X$.
A complete classification of $E$ is a map $c: X \rightarrow I$

$$
x E y \Longleftrightarrow c(x)=c(y)
$$

Some "bad" examples:


- $c: X / E \rightarrow X$ choice function $c\left([x]_{E}\right) \in[x]_{E}$. (Not definable)
$-x \mapsto[x]_{E}$. (Hard to describe $c(x)$ from $x$ )


## Complete classifications

Let $E$ be an equivalence relation on $X$.
A complete classification of $E$ is a map $c: X \rightarrow I$

$$
x E y \Longleftrightarrow c(x)=c(y)
$$

Some "bad" examples:


- $c: X / E \rightarrow X$ choice function $c\left([x]_{E}\right) \in[x]_{E}$. (Not definable)
- $x \mapsto[x]_{E}$. (Hard to describe $c(x)$ from $x$ )

Say that $c$ is absolute if:

- $c$ is definable (set theoretically).
- c remains a complete classification in generic extensions.


## Complete classifications

Let $E$ be an equivalence relation on $X$.
A complete classification of $E$ is a map $c: X \rightarrow I$

$$
x E y \Longleftrightarrow c(x)=c(y)
$$

Some "bad" examples:


- $c: X / E \rightarrow X$ choice function $c\left([x]_{E}\right) \in[x]_{E}$. (Not definable)
- $x \mapsto[x]_{E}$. (Hard to describe $c(x)$ from $x$ )

Say that $c$ is absolute if:

- $c$ is definable (set theoretically).
- $c$ remains a complete classification in generic extensions.
- $c(x)^{W}=c(x)^{W[G]}$ for $x \in W$. ("local computation")


## Complete classifications

Let $E$ be an equivalence relation on $X$.
A complete classification of $E$ is a map $c: X \rightarrow I$

$$
x E y \Longleftrightarrow c(x)=c(y)
$$

Some "bad" examples:


- $c: X / E \rightarrow X$ choice function $c\left([x]_{E}\right) \in[x]_{E}$. (Not definable)
- $x \mapsto[x]_{E}$. (Hard to describe $c(x)$ from $x$ )

Say that $c$ is absolute if:

- $c$ is definable (set theoretically).
- c remains a complete classification in generic extensions.
- $c(x)^{W}=c(x)^{W[G]}$ for $x \in W$. ("local computation")
$E, F$ E.R.s on Polish spaces $X, Y . f: X \rightarrow Y$ is a reduction if

$$
x E y \Longleftrightarrow f(x) F f(y)
$$

$E$ is Borel reducible to $F, E \leq_{B} F$, if there is a Borel reduction.

## Complete classifications

Let $E$ be an equivalence relation on $X$.
A complete classification of $E$ is a map $c: X \rightarrow I$

$$
x E y \Longleftrightarrow c(x)=c(y)
$$

Some "bad" examples:


- $c: X / E \rightarrow X$ choice function $c\left([x]_{E}\right) \in[x]_{E}$. (Not definable)
- $x \mapsto[x]_{E}$. (Hard to describe $c(x)$ from $x$ )

Say that $c$ is absolute if:

- $c$ is definable (set theoretically).
- c remains a complete classification in generic extensions.
- $c(x)^{W}=c(x)^{W[G]}$ for $x \in W$. ("local computation")
$E, F$ E.R.s on Polish spaces $X, Y . f: X \rightarrow Y$ is a reduction if

$$
x E y \Longleftrightarrow f(x) F f(y)
$$

$E$ is Borel reducible to $F, E \leq_{B} F$, if there is a Borel reduction.
$\Longrightarrow$ Classifying invariants for $F$ can be used to classify $E$.

## An extremely partial picture of Borel equivalence relations



## An extremely partial picture of Borel equivalence relations



## Generically absolute classifications

Definition: $c: X \rightarrow I$ a definable complete classification of $E$. Say that $c$ is generically absolute if

- it remains a complete classification in a Cohen-real extension.
- $c(x)^{W}=c(x)^{W[G]}$ for $x \in W$.


## Generically absolute classifications

Definition: $c: X \rightarrow I$ a definable complete classification of $E$. Say that $c$ is generically absolute if

- it remains a complete classification in a Cohen-real extension.
- $c(x)^{W}=c(x)^{W[G]}$ for $x \in W$.

Main point: allow some non-orbit relations to "be classifiable" too, while preserving the intuitions about classifications by countable structures.

## Generically absolute classifications

Definition: $c: X \rightarrow I$ a definable complete classification of $E$. Say that $c$ is generically absolute if

- it remains a complete classification in a Cohen-real extension.
- $c(x)^{W}=c(x)^{W[G]}$ for $x \in W$.

Main point: allow some non-orbit relations to "be classifiable" too, while preserving the intuitions about classifications by countable structures.
Theorem

1. $E_{1}$ is generically classifiable. (Using $\mathfrak{b}$ many of $E_{0}$-classes.)
A. Choice fails in $M$. (for $\mathfrak{b}$-sequences of $E_{0}$-classes)

## Generically absolute classifications

Definition: $c: X \rightarrow I$ a definable complete classification of $E$. Say that $c$ is generically absolute if

- it remains a complete classification in a Cohen-real extension.
- $c(x)^{W}=c(x)^{W[G]}$ for $x \in W$.

Main point: allow some non-orbit relations to "be classifiable" too, while preserving the intuitions about classifications by countable structures.
Theorem

1. $E_{1}$ is generically classifiable. (Using $\mathfrak{b}$ many of $E_{0}$-classes.)
A. Choice fails in $M$. (for $\mathfrak{b}$-sequences of $E_{0}$-classes)
2. $E_{1}$ does not admit an absolute classification.
B. $M=V(A)$ for a set (of reals) $A$.

## Generically absolute classifications

Definition: $c: X \rightarrow I$ a definable complete classification of $E$. Say that $c$ is generically absolute if

- it remains a complete classification in a Cohen-real extension.
- $c(x)^{W}=c(x)^{W[G]}$ for $x \in W$.

Main point: allow some non-orbit relations to "be classifiable" too, while preserving the intuitions about classifications by countable structures.
Theorem

1. $E_{1}$ is generically classifiable. (Using $\mathfrak{b}$ many of $E_{0}$-classes.)
A. Choice fails in $M$. (for $\mathfrak{b}$-sequences of $E_{0}$-classes)
2. $E_{1}$ does not admit an absolute classification.
B. $M=V(A)$ for a set (of reals) $A$.
3. $E_{1}$ is not gen. class. using $<\boldsymbol{\operatorname { a d d }}(\mathcal{B})$ many $E_{0}$-classes.
C. An analysis of reals in $M$. (Question: Does $M \models \mathrm{DC}_{<\operatorname{add}(\mathcal{B})}$ ?)

## Generically absolute classifications

Definition: $c: X \rightarrow I$ a definable complete classification of $E$. Say that $c$ is generically absolute if

- it remains a complete classification in a Cohen-real extension.
- $c(x)^{W}=c(x)^{W[G]}$ for $x \in W$.

Main point: allow some non-orbit relations to "be classifiable" too, while preserving the intuitions about classifications by countable structures.
Theorem

1. $E_{1}$ is generically classifiable. (Using $\mathfrak{b}$ many of $E_{0}$-classes.)
A. Choice fails in $M$. (for $\mathfrak{b}$-sequences of $E_{0}$-classes)
2. $E_{1}$ does not admit an absolute classification.
B. $M=V(A)$ for a set (of reals) $A$.
3. $E_{1}$ is not gen. class. using $<\boldsymbol{\operatorname { a d d }}(\mathcal{B})$ many $E_{0}$-classes.
C. An analysis of reals in $M$. (Question: Does $M \models \mathrm{DC}_{<\operatorname{add}(\mathcal{B})}$ ?)

Question: is (1) optimal? Cichon-Pawlikowsky: $\mathfrak{b}^{V[x]}=\boldsymbol{\operatorname { a d d }}(\mathcal{B})^{V}$

## Classifying invariants for $E_{1}$

$-E_{1}$ on $\left(2^{\omega}\right)^{\omega}, x E_{1} y \Longleftrightarrow(\exists n)(\forall m>n) \times(m)=y(m)$.

## Classifying invariants for $E_{1}$

- $E_{1}$ on $\left(2^{\omega}\right)^{\omega}, x E_{1} y \Longleftrightarrow(\exists n)(\forall m>n) x(m)=y(m)$.
- Fix $x \in\left(2^{\omega}\right)^{\omega}$. Given $f \in \omega^{\omega}$, Let $[x \upharpoonright f]$
be the set of all finite changes of $x \mid f$. $\quad x$
This is $E_{1}$-invariant. ( $[x \upharpoonright f]$ is an $E_{0}$-class.)

$$
\begin{array}{lllll}
1 & 0 & 1 & 1 & 0 \\
0 & 1 & 1 & 1 & 1 \\
1 & 1 & 0 & 0 & 1 \\
1 & 0 & 0_{f} & 0 & 0 \\
1 & 1 & 0 & 0 & 1 \\
\hline 0 & 1 & 1 & 1 & 0
\end{array}
$$

## Classifying invariants for $E_{1}$

- $E_{1}$ on $\left(2^{\omega}\right)^{\omega}, x E_{1} y \Longleftrightarrow(\exists n)(\forall m>n) x(m)=y(m)$.
- Fix $x \in\left(2^{\omega}\right)^{\omega}$. Given $f \in \omega^{\omega}$, Let $[x \upharpoonright f]$
be the set of all finite changes of $x \upharpoonright f$. $\quad x$
This is $E_{1}$-invariant. ( $[x \upharpoonright f]$ is an $E_{0}$-class.)

$$
\begin{array}{lllll}
1 & 0 & 1 & 1 & 0 \\
0 & 1 & 1 & 1 & 1 \\
1 & 1 & 0 & 0 & 1 \\
1 & 0 & 0_{f} & 0 & 0 \\
1 & 1 & 0 & 0 & 1 \\
\hline 0 & 1 & 1 & 1 & 0
\end{array}
$$

## Classifying invariants for $E_{1}$

- $E_{1}$ on $\left(2^{\omega}\right)^{\omega}, x E_{1} y \Longleftrightarrow(\exists n)(\forall m>n) x(m)=y(m)$.
- Fix $x \in\left(2^{\omega}\right)^{\omega}$. Given $f \in \omega^{\omega}$, Let $[x \upharpoonright f]$
be the set of all finite changes of $x \upharpoonright f$. $x$
This is $E_{1}$-invariant. ( $[x \upharpoonright f]$ is an $E_{0}$-class.)

| 1 | 0 | 1 | 1 | 0 |
| :--- | :--- | :--- | :--- | :--- |
| 0 | 1 | 1 | 1 | 1 |
| 1 | 1 | 0 | 0 | 1 |
| 1 | 0 | $0_{f}$ | 0 | 0 |
| 1 | 1 | 0 | 0 | 1 |
|  |  |  |  |  |
| 0 | 1 | 1 | 1 | 0 | model in which $\left\langle f_{\alpha} \mid \alpha<\mathfrak{b}\right\rangle$ is unbounded.

(In particular, in a Cohen-real extension.)

## Classifying invariants for $E_{1}$

- $E_{1}$ on $\left(2^{\omega}\right)^{\omega}, x E_{1} y \Longleftrightarrow(\exists n)(\forall m>n) x(m)=y(m)$.
- Fix $x \in\left(2^{\omega}\right)^{\omega}$. Given $f \in \omega^{\omega}$, Let $[x \upharpoonright f]$
be the set of all finite changes of $x \mid f$. $\quad x$
This is $E_{1}$-invariant. ( $[x \upharpoonright f]$ is an $E_{0}$-class.)


Fix $\left\langle f_{\alpha} \mid \alpha<\mathfrak{b}\right\rangle,<^{*}$-unbdd, $f_{\alpha}$ increasing.
Claim
$x \mapsto\left\langle\left[x \mid f_{\alpha}\right] \mid \alpha<\mathfrak{b}\right\rangle$ is a complete
classification of $E_{1}$.
Moreover, this is true in any model in which $\left\langle f_{\alpha} \mid \alpha<\mathfrak{b}\right\rangle$ is unbounded.
(In particular, in a Cohen-real extension.)
Note: Given Cohen-generic $x,\left\langle\left[x \upharpoonright f_{\alpha}\right] \mid \alpha<\mathfrak{b}\right\rangle \in M$.
Claim
$\left\langle\left[x \mid f_{\alpha}\right] \mid \alpha<\mathfrak{b}\right\rangle$ has no choice function in $M$.

## Classifying invariants for $E_{1}$

- $E_{1}$ on $\left(2^{\omega}\right)^{\omega}, x E_{1} y \Longleftrightarrow(\exists n)(\forall m>n) x(m)=y(m)$.
- Fix $x \in\left(2^{\omega}\right)^{\omega}$. Given $f \in \omega^{\omega}$, Let $[x \upharpoonright f]$
be the set of all finite changes of $x \mid f$. $\quad x$
This is $E_{1}$-invariant. ( $[x \upharpoonright f]$ is an $E_{0}$-class.)


Fix $\left\langle f_{\alpha} \mid \alpha<\mathfrak{b}\right\rangle,<^{*}$-unbdd, $f_{\alpha}$ increasing.
Claim
$x \mapsto\left\langle\left[x \mid f_{\alpha}\right] \mid \alpha<\mathfrak{b}\right\rangle$ is a complete
classification of $E_{1}$.
Moreover, this is true in any model in which $\left\langle f_{\alpha} \mid \alpha<\mathfrak{b}\right\rangle$ is unbounded.
(In particular, in a Cohen-real extension.)
Note: Given Cohen-generic $x,\left\langle\left[x \upharpoonright f_{\alpha}\right] \mid \alpha<\mathfrak{b}\right\rangle \in M$.
Claim
$\left\langle\left[x \mid f_{\alpha}\right] \mid \alpha<\mathfrak{b}\right\rangle$ has no choice function in $M$.

