I/O Logic

Leendert (Leon) van der Torre

Joint work with David Makinson and Xavier Parent
Layout of this talk

Input/output logic

1. Motivation: DSDL family
2. Motivation: Makinson@DEON98
3. Unconstrained
4. Permission
5. Constrained
6. Challenges
“Exotic Logics”

dyadic deontic logic: DSDL family

rational choice theory

non-monotonic logic

logic for counterfactuals


Related to the area of preference logic
Language DSDL family

\[ A ::= p \mid \neg A \mid A \land B \mid \Box A \mid \Box(B/A) \mid P(B/A) \]

New building blocks

- \( \Box(B/A) = B \) is obligatory, given \( A \)
- \( P(B/A) = B \) is permitted, given \( A \)

- Counterfactual logics \( A \Rightarrow B \), or
- Non-monotonic logic \( A \mid \neg B \)

Relation (some) preference logics:
- \( A \geq B = \neg O(\neg A \mid A \lor B) \) and \( O(A \mid B) = (A \land B) > (\neg A \land B) \)

Language DSDL family

\[ A ::= p \mid \neg A \mid A \land B \mid \square A \mid \bigcirc(B/A) \mid P(B/A) \]

New building blocks

- \( \bigcirc(B/A) = B \) is obligatory, given \( A \)
- \( P(B/A) = B \) is permitted, given \( A \)

May also be written as:

- Counterfactual logics \( A \Rightarrow B \), or
- Non-monotonic logic \( A \not\rightarrow B \)

Relation (some) preference logics:

- \( A \geq B = \neg O(\neg A|A \lor B) \) and \( O(A|B) = (A \land B) > (\neg A \land B) \)

Model DSDL family

Model

\[ M = (W, \geq, V), \text{ with} \]

- \( W \): a set of possible worlds \( \{x, y, \ldots\} \)
- \( \geq \): binary relation ranking all possible worlds in betterness
  - \( x \geq y \): \( x \) is at least as good as \( y \)
- \( V \): valuation function as usual

Note: the ranking can be made world-relative too.
Evaluation rules DSDL family

Evaluation rules

\[ M, x \models \bigcirc(B/A) \text{ iff } \text{opt}_\preceq(\|A\|) \subseteq \|B\| \]
\[ M, x \models P(B/A) \text{ iff } \text{opt}_\preceq(\|A\|) \cap \|B\| \neq \emptyset \]

where

- \( \|A\| = \{ x \in M : x \models A \} \)
- \( \text{opt}_\preceq(X) = \{ x \in X : (\forall y \in X)x \geq y \} \)

\( P \) dual of \( \bigcirc \), i.e., \( P(B/A) = \neg \bigcirc(\neg B/A) \)
Classes of structures DSDL

Constraints on $\geq$

**Reflexivity:** $x \geq x$

**Transitivity:** $x \geq y$ and $y \geq z$ implies $x \geq z$

**Totalness:** $x \geq y$ or $y \geq x$

**Limit assumption:** no infinite sequence of strictly better worlds

$$\|A\| \neq \emptyset \rightarrow \text{opt}_{\geq}(\|A\|) \neq \emptyset$$

<table>
<thead>
<tr>
<th></th>
<th>constraints on $\geq$</th>
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</thead>
<tbody>
<tr>
<td>DSDL1</td>
<td>reflexivity</td>
</tr>
<tr>
<td>DSDL2</td>
<td>reflexivity, and limit assumption</td>
</tr>
<tr>
<td>DSDL3</td>
<td>reflexivity, transitivity, totalness, and limit assumption</td>
</tr>
</tbody>
</table>

Table 1: Hansson 1969’s systems
Full axiomatization Total order case
Åqvist's System G

All truth functional tautologies (PL)
S5-schemata for □ and ◊ (S5)

\[ P(B/A) \leftrightarrow \neg \bigcirc (\neg B/A) \] (DfP)

\[ \bigcirc (B \rightarrow C/A) \rightarrow (\bigcirc(B/A) \rightarrow \bigcirc(C/A)) \] (COK)

\[ \bigcirc (B/A) \rightarrow \square \bigcirc (B/A) \] (Abs)

\[ \square A \rightarrow \bigcirc(A/B) \] (CON)

\[ \square(A \leftrightarrow B) \rightarrow (\bigcirc(C/A) \leftrightarrow \bigcirc(C/B)) \] (Ext)

\[ \bigcirc (A/A) \] (Id)

\[ \bigcirc (C/A \land B) \rightarrow \bigcirc(B \rightarrow C/A) \] (C)

\[ \bigcirc A \rightarrow (\bigcirc(B/A) \rightarrow P(B/A)) \] (D\( \star \))

\[ (P(B/A) \land \bigcirc(B \rightarrow C/A)) \rightarrow \bigcirc(C/A \land B) \] (S)

If \( \vdash A \) and \( \vdash A \rightarrow B \) then \( \vdash B \) (MP)

If \( \vdash A \) then \( \vdash \square A \) (N)
Selected bibliography (1)


Selected bibliography (2)

- D. Lewis, Counterfactuals, 1973, Blackwells.
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Deontic logic—as I see it

Does not even mention preferences:

- “[The philosophical aspects] have made me feel more and more like a lonely wolf . . .”
- “Logic has a wider reach than truth.”
- “The only acceptable answer I can think of must make reference to the purpose or rationale of norm giving activity.”
- “A consistent set of norms entails a further norm if, and only if, adding to the set the negation norm of this further norm makes the set inconsistent.”
- “A problem child in the philosophy of norms has been the notion of permission.”
A fundamental problem of deontic logic

- Jorgensens dilemma (1931)
  “A fundamental problem of deontic logic, we believe, is to reconstruct it in accord with the philosophical position that norms direct rather than describe, and are neither true nor false.”
  “No logic of norms without attention to a system of which they form part.” (iterative approach)

- “Validation of formulae $O(b/b)$ whose intuitive standing is open to question.”

- “It is rather difficult to construct an account of what is known as strong or positive permission along the same lines”

- Mobius strip (from nonmonotonic logic) $O(\neg a|c), O(c|b), O(b|a)$ in context $a$
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Language

- A conditional obligation is a pair \((a, x)\), called a generator
- \(a\) and \(x\) are propositional formulae
- \((a, x)\) is a rule; \(a\) is called the **body** and \(x\) is called the **head**
- A normative system \(N\) is a set of such pairs

Methodology: Develop examples and let the theory emerge
Semantics based on detachment

The semantics is ‘operational’

\[ x \in \text{out}(N, A) \]

- Calculates whether according to normative system \( N \) and in context \( A \), a formula \( x \) is obligatory
- \( A \) is the input (a set of wffs); \( x \) is the output
- Detachment as a core mechanism

Modus-ponens

(i) If \( a \), then \( x \)
(ii) \( a \)
(iii) So, \( x \)

Boghossian: this is constitutive of the notion of conditional

Detachment

- the only assumption made in IOL
- can hardly be challenged

DSDL

- extra assumptions
- potentially prone to criticisms
  - maximizing
  - trichotomy of value relations
(1) **Factual detachment**

(i) If $a$ is the case, then $x$ is obligatory

(ii) $a$ is the case

(iii) So, $x$ is obligatory

In the I/O notation:

$$\text{If } (a, x) \in N \text{ then } x \in \text{out}(N, a)$$

$N$: a set of pairs of propositional wffs (conditional norms)

$out(N, a)$: output of $a$ under $N$.

![Diagram](image.png)

**Figure 1:** Factual detachment
Simple-minded output operation $out_1$

Simple-minded output, $out_1$

\[ G(X) =_{df} \{ x : (a, x) \in N \text{ for some } a \in X \} \]

\[ out_1(N, A) =_{df} Cn(G(Cn(A))) \]
Simple-minded output operation \( out_1 \)

Simple-minded output, \( out_1 \)

\[
G(X) = df \{ x : (a, x) \in N \text{ for some } a \in X \}
\]

\[
out_1(N, A) = df \ Cn(G(Cn(A))
\]

<table>
<thead>
<tr>
<th>( N )</th>
<th>( A )</th>
<th>( Cn(A) )</th>
<th>( G(Cn(A)) )</th>
<th>( Cn(G(Cn(A)) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>{ (a, x) }</td>
<td>a</td>
<td>( a, \ldots )</td>
<td>( x )</td>
<td>( Cn(x) )</td>
</tr>
<tr>
<td>{ (a \lor b, x) }</td>
<td>a</td>
<td>( a \lor b, \ldots )</td>
<td>( x )</td>
<td>( Cn(x) )</td>
</tr>
<tr>
<td>{ (a, x), (a, y) }</td>
<td>a</td>
<td>( a, \ldots )</td>
<td>( x, y )</td>
<td>( Cn(x, y) )</td>
</tr>
</tbody>
</table>
Proof-theory

Trick: \((a, x) \in \text{out}(N)\) in place of \(x \in \text{out}(N, a)\).

Derivation

\((a, x)\) derivable from \(N\) - notation: \((a, x) \in \text{deriv}_1(N)\) — iff \((a, x)\) is in the least superset of \(N\) that includes \((\top, \top)\) and is closed under the rules of the system.
Rules

\[
\begin{align*}
(\text{SI}) & \quad \frac{(a, x) \quad b \vdash a}{(b, x)} \\
(\text{WO}) & \quad \frac{(a, x) \quad x \vdash y}{(a, y)} \\
(\text{AND}) & \quad \frac{(a, x) \quad (a, y)}{(a, x \land y)}
\end{align*}
\]

Table 2: IOL system

<table>
<thead>
<tr>
<th>Output operation</th>
<th>Rules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple-minded ((out_1))</td>
<td>{SI, WO, AND}</td>
</tr>
</tbody>
</table>

Completeness theorem

\(x \in out_1(N, a)\) iff \((a, x)\) derivable from \(N\) using these rules
Unpacking $out_1$

$x \in Cn(G(Cn(A)))$ means

$A \vdash a_1 \land ... \land a_n$

$(a_1, x_1), ..., (a_n, x_n)$ in $N$

and $x_1 \land ... \land x_n \vdash x$
Some other I/O operations

- $out_2$: basic output
- $out_3$: reusable simple-minded
- $out_4$: reusable basic

\[
\begin{align*}
\text{(SI)} & \quad \frac{(a, x)}{(b, x)} & b \vdash a \\
\text{(AND)} & \quad \frac{(a, x)}{(a, x \land y)} & (a, y) \\
\text{(CT)} & \quad \frac{(a, x)}{(a \land x, y)} & (a, y) \\
\text{(WO)} & \quad \frac{(a, x)}{(a, y)} & x \vdash y \\
\text{(OR)} & \quad \frac{(a, x)}{(a \lor b, x)} & (b, x)
\end{align*}
\]

Table 3: IOL systems

<table>
<thead>
<tr>
<th>Output operation</th>
<th>Rules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple-minded ($out_1$)</td>
<td>${\text{SI, WO, AND}}$</td>
</tr>
<tr>
<td>Basic ($out_2$)</td>
<td>${\text{SI, WO, AND}} + {\text{OR}}$</td>
</tr>
<tr>
<td>Reusable simple-minded ($out_3$)</td>
<td>${\text{SI, WO, AND}} + {\text{CT}}$</td>
</tr>
<tr>
<td>Reusable basic ($out_4$)</td>
<td>${\text{SI, WO, AND}} + {\text{OR, CT}}$</td>
</tr>
</tbody>
</table>
Basic output, \textit{out}_2

Call a set \( V \) of wffs complete iff: \( V = L \) (the set of all wffs) or \( V \) maximal consistent.

Basic output

\[
\text{out}_2(N, A) = \bigcap \{ Cn(G(V)) : A \subseteq V, V \text{ complete} \}
\]

One of these \( V_i \) is \( L \).
The others are maximal consistent extension (MCE) of \( A \)
Reasoning by cases

\[ \text{out}_2(N, A) = \bigcap \{ Cn(G(V)) : A \subseteq V, V \text{ complete} \} \]

\[ N = \{(a, x), (b, x)\}. \quad A = \{a \lor b\} \]

We have \text{out}_2(N, a \lor b) = Cn(x).

<table>
<thead>
<tr>
<th>(V)</th>
<th>(G(V))</th>
<th>(Cn(G(V)))</th>
</tr>
</thead>
<tbody>
<tr>
<td>(L)</td>
<td>{x}</td>
<td>(Cn(x))</td>
</tr>
<tr>
<td>MCE of {a \lor b}</td>
<td>{x}</td>
<td>(Cn(x))</td>
</tr>
</tbody>
</table>

Disjunction property: \(a \lor b\) in a MCE iff one of the disjuncts in it.
Iteration of successive detachments

(2) Deontic detachment

(i) If $a$ is obligatory, then $x$ is obligatory
(ii) $a$ is obligatory
(iii) So, $x$ is obligatory

In the I/O notation:

If $a \in out(N, T)$ and $(a, x) \in N$ then $x \in out(N, T)$

(a) $a$ detached

(b) $x$ detached

Figure 2: Iteration of successive detachments
Reusable output, $out_3$ and $out_4$

Reusable simple-minded output

$$out_3(N, A) = \cap \{ Cn(G(B)) : A \subseteq B = Cn(B) \supseteq G(B) \}$$

Reusable basic output

$$out_4(N, A) = \cap \{ Cn(G(V)) : A \subseteq V \supseteq G(V), V \text{ complete} \}$$
Example

Show that GC is a rule of $\text{deriv}_4$

\[
\begin{array}{c}
(a, b) \quad (\neg a, c) \\
\hline
(\neg c, b)
\end{array}
\]
Example

- Show that GC is a rule of deriv$_4$

\[
\frac{(a, b)}{(a, b)\quad (\neg a, c)}\quad (\neg a, c) \quad \frac{\neg c \land \neg a \land c, b}{\neg c \land \neg a, b} \quad \frac{\neg c \land \neg a, b}{\neg c, b} \quad \frac{\neg c, b}{\neg c, b} \quad (\neg c, b)
\]

\[
\frac{(a, b)}{(a, b)\quad (\neg a, c)}\quad (\neg c, b) \quad \frac{\neg c, b}{\neg c, b}
\]

In an intuitionistic setting the last move is blocked, because (‡) does not hold: \(\neg c \not\implies (\neg c \land \neg a \land c, b)\). If (‡) was valid, then (substituting \(\neg c\) for \(\neg c\)) we would get the law of excluded middle. Example 2 provides a counter-model to the former, which is also a counter-model to the latter.

Example 2. Consider a model \(M = (W, \geq, V)\) with \(W = \{s, t\}\), \(s \geq s\), \(t \geq t\), \(t \geq s\), \(V(a) = \{t\}\), and \(V(c) = \emptyset\). This can be depicted as in Figure 1. Here the general convention is that \(v \geq u\) iff either \(u = v\) or \(v\) is above \(u\). And each world is labelled with the atoms it makes true. Thus, a missing atom indicates falsehood.

\[
\text{Fig. 1 A counter-model to (‡) because neither s nor t forces c. s does not force (\neg c \land \neg a), because it does not force (\neg a) (witness: t). And neither does s force (\neg c \land a). Therefore, (\neg c \land \neg a) \lor (\neg c \land a)\) is not a semantic consequence of \(\neg c\), and thus (by soundness) the former is not derivable from the latter.
\]

As the reader may see, the fact that \(\neg c\) occurs in the premise in (‡) plays no role.

This is also a counter-model to the law of excluded middle. Indeed, \(a \lor \neg a\) is not forced at \(s\). Example 3 shows that (GC) fails in an intuitionistic setting.
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Permission

- It is permitted to drive at a speed of 95 km/h on a motorway
- Anyone over 18 can buy booze legally
Permission

- It is permitted to drive at a speed of 95 km/h on a motorway
- Anyone over 18 can buy booze legally

Negative permission

Let $N$ be a set of generators, and let $\text{out}$ be an input/output logic.

$$(a, x) \in \text{negperm}(N) \iff (a, \neg x) \not\in \text{out}(N)$$

Positive permission - static

Let $N$ and $P$ be two sets of generators, where $P$ stands for permissive norms, and let $\text{out}$ be an input/output logic.

$$(a, x) \in \text{statperm}(P, N) \iff (a, x) \in \text{out}(N \cup Q)$$

for some singleton or empty $Q \subseteq P$

$(a, x)$ is generated either by the obligations in $N$ alone, or by the norms in $G$ together with some explicit permission $(b, y)$ in $P$. 
Proof theory

Subverse of a rule: obtained by downgrading to permission status one of the premises, and also the conclusion of the rule.
Ex: subverse of AND is

\[(a, x)^o (a, y)^p \quad \frac{(a, x \land y)^p}{(a, x \land y)^p}\]

Observation
If \textit{out} satisfies a rule \(R\), then the corresponding \textit{statperm} satisfies its subverse.

Theorem
For each of the following rule-sets, the subverse set suffices to characterize the corresponding static permission operation.

1. \textit{out}_1 with its usual rules SI, WO, AND,
2. \textit{out}_2 with its usual rules, i.e. the above plus OR,
3. \textit{out}_3 with the rules SI, WO, CTA:

\[
(a, x), (a \land x, y) \quad \frac{(a, x \land y)}{(a, x \land y)}
\]
Permission

Positive permission - dynamic

\[(a, x) \in \text{dynperm}(P, N) \text{ iff } (c, \neg z) \in \text{out}(N \cup \{(a, \neg x)\})\]

for some \((c, z) \in \text{statperm}(P, N)\) with \(c\) consistent

Forbidding \(x\) under condition \(a\) would prevent the agent from making use of some explicit (static) permission \((c, z)\).
\((a, x)\) protected by the code.
Permission

Positive permission - dynamic
Danish’s caricatures of the prophet Mohammed
freedom of speech
banning

\[(a, x) \in \text{dynperm}(P, N) \quad \text{iff} \quad (c, \neg z) \in \text{out}(N \cup \{(a, \neg x)\})\]
for some \((c, z) \in \text{statperm}(P, N)\) with \(c\) consistent

Forbidding \(x\) under condition \(a\) would prevent the agent from making use of some explicit (static) permission \((c, z)\).
\((a, x)\) protected by the code.
Proof theory

Inverse of a rule: obtained by downgrading to permission status one of the premises, and also the conclusion of the rule, swapped them, and negating both their heads.
Ex: inverse of AND is

\[
\frac{(a, x)^o \ (a, \neg(x \land y))^p \ (a, \neg y)^p}{(a, x)^o \ (a, \neg (x \land y))^p}
\]

Observation
If \textit{out} satisfies a rule \( R \), then the corresponding \textit{negperm} and \textit{dynperm} satisfy its subverse.

Theorem
For each of the following rule-sets, the inverse set suffices to characterize the corresponding dynamic permission operation.

1. \(\textit{out}_1\) with its usual rules SI, WO, AND,
2. \(\textit{out}_2\) with its usual rules, i.e. the above plus OR,
3. \(\textit{out}_3\) with the rules SI, WO, CTA.
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Constrained I/O Logic (cIOL)

Problems

- uIOL not conflict-tolerant
  \[ N_1 = \{(a, b), (a, \neg b)\} \quad \text{input: } a \text{ - output: } L \quad \text{Explosion!!} \]
Constrained I/O Logic (cIOL)

Problems

- uIOL not conflict-tolerant
  \[ N_1 = \{(a, b), (a, \neg b)\} \quad \text{input: } a \quad \text{output: } L \quad \text{Explosion!!} \]

- uIOL not violation-tolerant
  \[ N_2 = \{(\top, \neg a), (\neg a, \neg b), (a, b)\} \quad \text{input: } a \quad \text{output: } L \quad \text{Explosion!!} \]
Constrained I/O Logic (cIOL)

Problems

▶ uIOL not conflict-tolerant

\[ N_1 = \{(a, b), (a, \neg b)\} \quad \text{input: } a \text{ - output: } L \quad \text{Explosion!!} \]

▶ uIOL not violation-tolerant

\[ N_2 = \{\top, \neg a), (\neg a, \neg b), (a, b)\} \quad \text{input: } a \text{ - output: } L \quad \text{Explosion!!} \]

Threshold idea

▶ Cut back the set of generators in \( N \) to just below the threshold of yielding excess
Norm violation

- **C**: a set of additional formulae called ‘constraints’. The output must be consistent with it.
- For CTDs, $C = A$.

Maxfamily

- $maxfamily(N, A, C)$ is the set of $\subseteq$-maximal subsets $N'$ of $N$ such that $out(N', A)$ is consistent with $C$.
- $outfamily(N, A, C) = \{out(N', A) | N' \in maxfamily(N, A, C)\}$.
- $x \in out_{\cup/\cap}(N, A)$ iff $x \in \cup/\cap outfamily(N, A, C)$
Chisholm example

$h$: help; $t$: tell

$N = \{(\top, h), (h, t), (\neg h, \neg t)\}$

$A = \{\neg h\}$
Chisholm example

\[ N = \{(\top, h), (h, t), (\neg h, \neg t)\} \]

\[ A = \{\neg h\} \]

\[ \text{maxfamily}(N, A, A) = \{\{2, 3\}\} \quad \text{and} \]

\[ \text{out}_{\cup/\cap}(N, A) = Cn(\neg t) \]
Chisholm example

\[ N = \{ (\top, h), (h, t), (\neg h, \neg t) \} \]

\[ A = \{ \neg h \} \]

\[ \text{maxfamily}(N, A, A) = \{ \{ 2, 3 \} \} \text{ and } \]
\[ \text{out}_{\cup/\cap}(N, A) = Cn(\neg t) \]

\[ A = \{ h \} \]

\[ \text{maxfamily}(N, A, A) = \{ \{ 1, 2, 3 \} \} \text{ and } \]
\[ \text{out}_{\cup/\cap}(N, A) = Cn(h, t) \]
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Challenges

1. Drowning problem
2. Priorities and other extensions
3. Norm change
4. Dichotomy unconstrained/constrained and strong equivalence
5. Framework and requirements
## Requirements

| FD | \((\alpha, \beta) \in N \Rightarrow \beta \in out(N, \alpha)\) | Factual Detachment |
| VD | \((A, \beta) \Rightarrow (A \cup \{\neg \beta\}, \beta)\) | Violation Detection |
| SUB | \(\alpha \in out(N, A) \Rightarrow \alpha[\sigma] \in out(N[\sigma], A[\sigma])\) | Substitution |
| RLE | \(N \approx M, Cn(A) = Cn(B), Cn(\alpha) = Cn(\beta), (A, \alpha) \in out(N) \Rightarrow (B, \beta) \in out(M)\) | Replacement of equivalents |
| IMP | \(out(N, A) \subseteq Cn(m(N) \cup A)\) | Implication |
| PC | \(\alpha \in \overline{V}(N, A) \Rightarrow \exists M \subseteq N : \alpha \in out(M, A)\) and \(out(M, A) \cup A\) consistent | Paraconsistency |
| AND | \((A, \alpha)(A, \beta) \Rightarrow (A, \alpha \land \beta)\) | Conjunction |
| FM | \((A, \alpha) \Rightarrow (A \cup B, \alpha)\) | Factual monotony |
| NM | \(out(N) \subseteq out(N \cup M)\) | Norm monotony |
| NI | \(M \subseteq O(N) \Rightarrow O(N) = O(N \cup M)\) | Norm Induction |
From The Eugene Guard, April 14, 1925, page 7

(Eugene, Oregon, U.S.A.)

IF YOU BUMP, DO IT NICELY, IS PLEASE

World peace, safety, proficiency, high-blood pressure and property depend on the etiquette with which motorists bump and get bumped.

"If you must bump be courteous," says the American Chalm company in a new booklet on the "Etiquette of Bumping." "Etiquette requires bumpers on all cars—bumper which will ward off without damage the blow on collision, the side book, the undercut, the over reach and the fender crumpling body blow."

The undershot bus must take its bumping fenders, its deflated gas tank, its battered radiator to the side streets where two-fisted drivers seeking damages are unrestrained by the rules of bumper etiquette.

Choose your bumper carefully. Inasmuch as collisions are part of the suspension system, no matter what happens, just keep driving.

New Motorcycle Has Hand Clutch

Contrary to the general mechanical systems of American motorcycles, the new Prince motorcycle, latest addition to the Indian Line, has clutch operated by hand lever which is on the left handlebar, instead of at foot board on left side of machine. In this way, with the gas control also on the left handlebar, manipulation of controls is much simplified making for easier riding, according to H. W. Armstrong, mechanical instructor at the Indian school at Springfield, Mass.

Mr. Armstrong asserts that another feature of this new machine is its phenomenal economy. He resides a little over three miles from his place of business and in riding his Prince back and forth to work averages about seven miles a day. In two and one-half weeks time, he claims, he has used only one-gallon of gasoline; whereas prior to purchasing the motorcycle he was using a four-wheeled vehicle for his daily trips and during the same period, five gallons of gasoline were consumed.
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