Inferring Accumulative Effects of Higher Order Programs

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Many temporal safety properties of higher-order programs go beyond simple event sequencing and require an automaton register (or "accumulator") to express, such as input-dependency, event summation, resource usage, ensuring equal event magnitude, computation cost, etc. Some steps have been made towards verifying more basic temporal event sequences via reductions to fair termination Murase et al. [26] or some input-dependent properties through deductive proof systems Nanjo et al. [27]. However, there are currently no automated techniques to verify the more general class of register-automaton safety properties of higher-order programs.

We introduce an abstract interpretation-based analysis to compute dependent, register-automata effects of recursive, higher-order programs. We capture properties of a program's effects in terms of automata that summarizes the history of observed effects using an accumulator register. The key novelty is a new abstract domain for context-dependent effects, capable of abstracting relations between the program environment, the automaton control state, and the accumulator value. The upshot is a dataflow type and effect system that computes context-sensitive effect summaries. We demonstrate our work via a prototype implementation that computes dependent effect summaries (and validates assertions) for OCaml-like recursive higher order programs. As a basis of comparison, we describe reductions to assertion checking for effect-free programs, and demonstrate that our approach outperforms prior tools DRIFT and RCAML/PCSAT. Overall, across a set of 21 new benchmarks, RCAML/PCSAT could not verify any, DRIFT verified 9 benchmarks, and evDRIFT verified 19; evDRIFT also had a 30.5× over DRIFT on those benchmarks that both tools could solve.

1 INTRODUCTION

The long tradition of temporal property verification has, in recent years, been also directed at programs written in languages with recursion and higher-order features. In this direction, a first step was to go beyond simple types to dependent and/or refinement type systems [9, 28, 31, 37, 40], capable of validating merely (non-temporal) safety assertions. Subsequently, works focused on verifying termination of higher-order programs, e.g., [21].

As a next step, researchers focused on *temporal* properties of higher-order programs. In this setting, programs have a notion of observable *events* or *effects* (e.g. [23]), typically emitted as a side effect of a program expression such as "ev e," where e is first reduced to a program value and then emitted. The semantics of the program is correspondingly augmented to reduce to a pair (v,π) , where v is the value and π is a sequence of events or an "event trace." For such programs a natural question is whether the set of all event traces is included within a given temporal property expressed in Linear Temporal Logic [29], or as an automaton. Liveness properties apply to programs that may diverge, inducing infinite event traces. A first approach at temporal verification was through the celebrated reduction to fair termination [38]. Murase et al. [26] introduced a reduction from higher-order programs and LTL properties to termination of a calling relation.

In a parallel research trend, others have been exploring compositional type-and-effect theories for temporal verification. Skalka and Smith [34], Skalka et al. [35] described a type-and-effect system to extract a finite abstraction of a program and then perform model-checking on that abstraction. Later, Koskinen and Terauchi [19] and Hofmann and Chen [13] showed that the effects

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component in a type-and-effect system $\Gamma \vdash e : \tau \& \varphi$ could consist of a temporal property φ to hold of the events generated by the reduction of expression e. This was combined with a dependent refinement system by Koskinen and Terauchi [19] and used with an abstraction of Büchi automata by Hofmann and Chen [13]. Nanjo et al. [27] then later gave a deductive proof system for verifying such temporal effects, even permitting the temporal effect expressions to depend on program inputs. In a more distantly related line of research, others consider languages with programmer-provided "algebraic effects" and their handlers [22, 32] (see Sec. 9).

There are, however, many temporal safety properties that go beyond basic event sequencing properties especially, for example, if each event emits an integer. Examples include a property that the sum of the emitted integers is below some bound, or that the last emitted integer is the largest one. Properties could depend on inputs (like some examples in Nanjo et al. [27]), or involve context-free-like properties such as the sum of production being equal to the sum of consumption. Despite the above discussed prior works, there are currently no automatic tools for verifying such kinds of temporal safety properties of higher-order programs with effects.

1.1 This Paper

We introduce a new route to automate temporal effect inference and verification of recursive higher-order programs through abstract interpretation over a novel *effect abstract domain*. To support the wider class of temporal safety properties mentioned, we first augment the property language to those expressible via a symbolic accumulator automaton (SAA). Our automaton model is inspired by the various notions of (symbolic) register or memory automata considered [3, 7, 16] and consists of a register "accumulator" (e.g., an integer or tuple of integers) that can remember earlier events, calculate summaries, etc. Symbolic accumulator automata capture properties such as maximum/minimum, summation, resource bounds, context-free protocols of stateful APIs, etc., in addition to simple event ordering properties expressible with a regular finite state automaton.

As a first step, we observe that verifying such properties of higher-order programs with effects can be reduced to verifying assertions of effect-less higher-order programs. We show that this can be done via one of at least two program transformations: (i) translating the program so that every expression reduces to a (value, effect prefix) tuple, where the second component accumulates the effects as a sort of ghost return value, or (ii) translating the program into continuation-passing style, accumulating the effect prefix as an argument. We later experimentally show that, although this theoretically enables higher-order safety verifiers (e.g. Drift and CoAR/MoCHi) to be applied to the effect setting, those tools do not exploit much of the property structure and ultimately struggle on the inherent product construction that comes from these transformations.

To achieve a more scalable solution, our core contribution is a novel effect abstract domain. In the concrete semantics, an execution is simply the program execution environment paired with the event trace prefix that was thus far generated, i.e., an element of $(V^* \times Env)$ where V is the domain of program values and Env the domain of value environments. We first observe that both the environment and the possible trace prefix, somewhat counterintuitively, can be organized around the automaton control state. That is, an abstraction like $Q \to \wp(V \times Env)$. captures the possible pairs of accumulator value and execution environment that could be reachable at a control state $q \in Q$ of the automaton. This control state-centric summary of environments enables the abstract domain to capture disjunctive invariants, guided by the target property of the verification. This abstraction often avoids the need for switching to a more expensive abstract domain that is closed under precise joins.

Having organized around control state, the final abstraction step is to associate with each q: (i) a summary of the program environment, e.g. constraints like x > y, (ii) a summary of the automaton accumulator, e.g. constraints like acc > 0, and even (iii) relations between the two, e.g.

acc > x - y. Thus, in this example, we capture at location ℓ in the program, that control state q is reachable but only in a configuration where the accumulator is positive, the program variable x is greater than y and the accumulator bounds the difference between x and y. The effect abstract domain can naturally be instantiated using any of a variety of standard numerical domains such as polyhedra [2, 6, 33], octagons [25], etc.

We remark that, in addition to addressing a class of safety properties that previous tools do not support, to our knowledge, our work is the first use of abstract interpretation toward inferring temporal effects of higher-order programs. In light of the promising results presented here, in future work we aim to further explore how abstract interpretation can provide an alternative route toward automating other classes of properties of higher-order programs such as liveness.

1.2 Challenges & Contributions

To pursue the effect abstract domain, we address a the following challenges in this paper:

Accumulative type and effect system (Sec. 4). Our effect abstract domain, expressing properties of program expressions, is associated with the program through a type-and-effect system. Unfortunately existing type and effect systems [13, 19, 27] are not suitable because their judgments of the form $\Gamma \vdash e : \tau \& \varphi$ do not involve event trace prefixes in their context: instead φ describes the effects of e alone, without information about what effects preceded the evaluation of e. While this makes the type system more compositional, it also makes effect inference more difficult because one has to analyze e for any possible prefix trace. In terms of our automata-based effect domain, it corresponds to analyzing e for an arbitrary initial control state and accumulator value. We thus present a new effect system, with judgments of the form Γ ; $\varphi \vdash e : \tau \& \varphi'$, where φ summarizes the prefix up to the evaluation of e, φ' summarizes the extended prefix with the evaluation of e, and term-specific premises dictate how extensions are formed. The system is parametric in the abstract domains used to express dependent effects and dependent type refinements.

Effect abstract domain (Sec. 5). We formalize the abstract domain discussed above as an instantiation of our effect system. A key ingredient is the effect extension operator \odot that takes an abstraction of a reachable automaton configuration ϕ , a type of a new event β (we use refinement types for β to capture precise information about the possible values of the event to extend a trace prefix), and produces an abstraction of the automaton configurations reachable by the extended trace. The user-provided automata include symbolic error state conditions and so if the effect computed by the analysis associates error states with bottom, then the property encoded by the automaton holds of the program. Finally, we have proved the soundness of the effect abstract domain.

Automated inference of effects (Sec. 6). We next address the question of automation. Recent work showed that, for programs without effects, that abstract interpretation can be used to compute refinement types through a higher-order dataflow analysis [28]. We present an extension to effectful programs through a translation-oriented embedding of programs with effects to effect-free programs. The resulting abstract interpretation propagates effects in addition to values through the program. To obtain the overall soundness of the inference algorithm, we show that the types inferred for the translated programs can be used to reconstruct a derivation in our type and effects system.

Verification, Implementation & Benchmarks (Sec. 7). We implement the type system, effect abstract domain and abstract interpretation in a new tool **ev**Drift for OCaml-like recursive higher-order programs. Our implementation is an extension of the Drift tool, which provides assertion checking of effect-free programs. There are no existing tools that can verify SAA properties of higher-order event-generating programs. Thus, in effort to find the closest basis for comparison, we also implemented two translations (one via encoding effects in tuples; another via encoding effects as

a CPS parameter) that reduce SAA verification of effect programs to assertion checking of effect-free programs (to which Drift, RCaml/PCSAT, etc. can be applied). To improve the precision of our abstract interpretation, we also adapted the classical notion of *trace partitioning* [24] to this higher-order effect setting.

To date there are limited higher-order benchmark programs with properties that require an automaton with a register to express. We thus built the first suite of such benchmarks by creating 21 new examples and adapting examples from the literature including summation/max-min/ examples [3, 7, 16], monotonicity examples, programs with temporal event sequences [19, 27], resource analysis [11, 12, 14], and an auction smart contract [36].

Evaluation (Sec. 8). We evaluated (i) the effectiveness of evDrift at directly verifying SAA-expressible temporal safety properties over the use of Drift and RCaml/PCSAT when applied via the translation/reduction to assertion checking, and (ii) the degree to which trace partitioning improves precision for evDrift. Overall, our approach is able to verify 19 out of the 21 benchmarks, which is 10 more than Drift (with our tuple translation) could verify, while RCaml/PCSAT could not verify any (with our cps translation and a 900s timeout). Furthermore, evDrift offered a speedup of 30.5× over Drift on the benchmarks that both could solve.

The supplement to this paper includes the ${f ev}$ DRIFT source, all benchmark sources, and the Appendix.

2 OVERVIEW

This paper introduces a method for verifying properties of dependent effects of higher-order programs, through an abstraction that can express relationships between the (symbolic) next step of an automaton and the dependent typing context of the program at the location where a next event is emitted. We show that, when combining our approach with data-flow abstract interpretation [28], and an abstract domain of symbolic accumulator automata, we can verify a variety of memory-based, dependent temporal safety properties of higher-order programs.

2.1 Motivating Examples

Example 2.1. Consider the following example:

```
1 let rec busy n t =

2 if (n <= 0) then ev (-t)

3 else busy (n - 1) t

4 let main (x:int) (n:int) =

5 ev x; busy n x

q_0
q_1
q_1
else
q_2
true
```

Above in main, an integer event x is emitted, and then a recursive function busy repeatedly iterates until n is below 0, at which point the event -t (which is equal to -x) is emitted. For this program, the possible event traces are simply $\bigcup_{x \in \mathbb{Z}} \{\{x, -x\}\}$, i.e., any two-element sequence of an integer and its negation. This property can be expressed by a *symbolic accumulator automaton* (a cousin to symbolic automata and to memory automata, as discussed in Sec. 5), as shown above. There is an initial control state q_0 , from which point, whenever an event $\operatorname{ev}(v)$ is observed for any integer v, the automaton's internal register acc is updated to store value v and a transition is taken to q_1 . From q_1 , observing another event whose value is exactly the negation of the saved acc will cause a transition to the final accepting state q_2 or otherwise loop at q_1 . This automaton actually accepts more traces: $\bigcup_{x \in \mathbb{Z}} \{\{x, \ldots, -x\}\}$, which permits arbitrary events between v and v.

2.2 Naïve approach: reduction to assertion checking

At least in theory, this program/property can be verified using existing tools through a cross-product transformation between the program and property that reduces the problem to an assertion-checking safety problem. As is common, the automaton can be encoded in the programming language (or the program can be converted to an automaton [10]) with integer variables q and acc for the automaton's control state and accumulator, respectively. The automaton's transition function is also encoded in the language through simple if-then-else expressions. This is shown

in the function ev_step function to the right, which consumes the current automaton configuration, and a next event value v and returns the next configuration.

A product can then be formed, for example, by passing and returning the (q,acc) configuration into and out of every expression, and replacing **ev** expressions (which are not meaningful to typical safety verifiers)

```
1 let ev_step q acc v : (Q * int) =
2  (* take one automaton step *)
3  if   (q==0) then (1, v)
4  else if (q==1 && v==-acc) then (2,acc)
5  else if (q==1) then (1,acc)
6  else (q,acc)
```

with a call to ev_step. For Ex. 2.1, this yields the following product program:

In main_prod above, the initial configuration is provided for the automaton, then the first event expression is replaced by a call to ev_step, then the resulting next configuration is passed to busy_prod and the returned final configuration is input to an assert. busy_prod is similar.

The above example is recursive and we are also interested in programs that are higher-order (though the above simple example is only first-order), which limits the field of applicable existing tools. One example is the DRIFT tool which uses a dependent type system and abstract interpretation to verify safety properties of higher-order recursive programs [28]. We implemented the above translation (details in Section 6.3). As part of its approach, DRIFT then converts the program to lambda calculus expressions, leading to a program that is much larger (roughly 75 lines of code). For this example DRIFT is able to verify the product encoding in 11.5s. By contrast, this paper will introduce an abstraction that can verify this program/property in 0.4s.

RCaml/PCSat (part of CoAR¹) is another fairly mature tool that can also verify assertions of higher order programs [17, 20, 32]. Currently RCaml/PCSat does not support tuples, so the above encoding cannot be used. Instead, we implemented a CPS translation that passes q and acc (along with k) as arguments. Unsurprisingly, for even small examples this translation quickly explodes and is 55 lines of code for Ex. 2.1 (the full CPS conversion is in Apx $\mathbb C$ of the supplement). Although RCaml/PCSat can parse and begin verification of these CPS-based encodings, it diverges and either runs out of time or memory.

The problem. Although this example tuple product reduction can be verified by existing tools, unsurprisingly, the approach does not scale well with DRIFT and does not work at all with RCAML/PCSAT. Let us examine another example called temperature, shown in the top left of Fig. 1, that is only slightly more involved yet causes DRIFT to timeout after 900s when the tuple product reduction is used. We will describe a technique and tool that can instead verify this example in 35s.

The temperature example in Fig. 1 can be thought of as a simple model of a thermostat, which can either be in a heating mode (when input v is even) or a cooling mode (when input v is odd).

¹https://github.com/hiroshi-unno/coar/

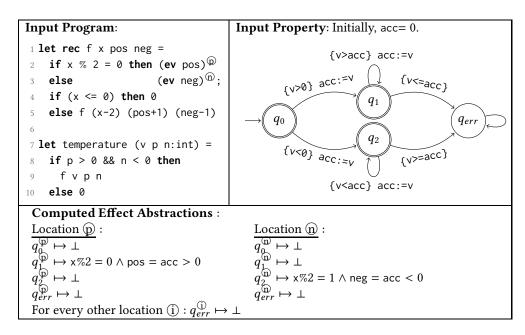


Fig. 1. In the top left is the input program temperature. The top right illustrates the symbolic accumulator automaton property specifying that, roughly, the system is either in heating mode (q=1) or cooling mode (q=2), with the events monotonically increasing in heating mode and decreasing in cooling mode. At the bottom is the effect abstraction that we automatically compute in this paper, discussed in this section.

Function f is initially called with x (i.e. v), and a positive integer pos, and negative integer neg. Whenever x is even, an event of value pos is emitted and the temperature is increased. Whenever x is odd, the value neg is emitted and neg is decreased. At each recursive call of f, x decreases by 2, so it will always either be even or odd. Thus, the event traces of the program are: $\bigcup_{x \in \mathbb{Z}^+} \{x, x + 1, x + 2, \ldots\} \bigcup \bigcup_{x \in \mathbb{Z}^-} \{x, x - 1, x - 2, \ldots\}$, i.e. any sequence of a monotonically increasing positive integer or any sequence of a monotonically decreasing negative integer. This property is captured by the accumulator automaton illustrated in the top right of Fig. 1. If the first event is positive, the upper arc is taken, and the value of the event is remembered in the accumulator. Thereafter, as long as each successive event is greater than the previous, the automaton loops at q_1 . Dually, if the initial event is negative and subsequent events monotonically decrease, the automaton loops at q_2 . If ever the monotonic increase/decrease is violated, a transition is taken to q_{err} .

The struggle. A naïve translation-based reduction to existing safety verification tools for higher-order programs does not fare well and the reason is twofold. First, there is a blowup in the size of the analyzed program due to the translation, which causes a significant increase in analysis time. In addition, tools like Drift use abstract domains that are not closed under arbitrary disjunctions. A naïve translation of the automaton's state space and transition relation into the program will cause loss of precision due to computation of imprecise joins at data-flow join points. This will cause the analysis to infer an effect abstraction that is too imprecise for verifying the desired property.

2.3 Effect Abstract Domain

The key idea of this paper is to exploit the structure of the automaton to better capture disjunctive reasoning in the abstract domain. Roughly speaking, the abstract domain will associate each *concrete* automaton control state q, with *abstractions* of (i) the event sequences that could lead to q

and (ii) the possible program environment at q. This abstraction is expressed as a relation between the accumulator value and the program environment. We will now describe this abstraction and see the resulting computed abstraction depicted in the bottom of Fig. 1.

We obtain this abstraction in three main steps, provided a given input symbolic accumulator automaton $A = (Q, \mathcal{V}, \delta, \text{acc}, \ldots)$ with the alphabet being some set of values \mathcal{V} (in this section let $\mathcal{V} = \mathbb{Z}$) and transitions updating the control state and accumulator. We now discuss these steps.

Concrete semantics. To begin, the concrete semantics of the program is simply pairs of event traces \mathbb{Z}^* with program environments, i.e., $\wp(\mathbb{Z}^* \times Env)$. Transitions in the concrete semantics naturally update the environment in accordance with the reduction rules, and the event sequence is only updated when an expression $\mathbf{ev}\ v$ is reduced: $\wp(\mathbb{Z}^* \times Env) \xrightarrow{\mathbf{ev}\ v} \wp(\mathbb{Z}^* \times Env)$. For the above example, a concrete sequence of states and transitions could be the following:

$$(\epsilon, [main, v:42, p:3, n:-8]) \sim (\epsilon, [f, x:42, pos:3, neg:-8]) \xrightarrow{\text{ev } 3} (3, [f, x:42, pos:3, neg:-8])$$

 $\sim (3, [f, x:40, pos:3, neg:-8]) \xrightarrow{\text{ev } 3} (3 \cdot 3, [f, x:40, pos:3, neg:-8]) \cdots$

(Technically a transition takes the powerset of possible sequence/environment pairs to another powerset; here we show only one sequence for simplicity.) Above the first component is an event sequence, starting with the empty sequence ϵ and, for this starting environment, the trace will accumulate the event sequence is $3 \cdot 3 \cdots$.

Intermediate abstraction via concrete automaton control states. With integer variables and integer effect sequences, it is clear that abstraction is needed to represent the possible event sequences of a program even as simple as this running example. The first key idea we explore in this paper is to organize the abstraction around the automaton and, crucially, keep the automaton control state concrete while abstracting everything else: the environment, the possible event sequence prefixes, and the value of the automaton's accumulator. The benefit is that this will lead to a somewhat disjunctive abstract effect domain, where event trace prefixes can be categorize according to the control state (and accumulator values and program environments) that those prefixes reach. To this end, the first layer of abstraction uses the automaton control states Q (rather than merely event sequences), and associates each automaton control state with the possible set of pairs of accumulator value \mathbb{Z} and program environment that reach that state along some event sequence: $Q \mapsto \wp(\mathbb{Z} \times Env)$. At this layer, transitions from an expression **ev** v are captured through the automaton's transition function $\delta(v)$, which leads to a (possibly) new automaton state and updates the accumulator value: $Q \mapsto \wp(\mathbb{Z} \times \mathit{Env}) \xrightarrow{\delta(v)} Q \mapsto \wp(\mathbb{Z} \times \mathit{Env})$. For the temperature example, when an execution involves positive temperatures and there is an event trace prefix such as $1 \cdot 2 \cdot 3$, then the following lists some of the effects at body of f per each *q*:

$$q_1 \mapsto \{(1, (x:42, pos:1, neg:_)), (2, (x:40, pos:2, neg:_)), \ldots\}, \quad q_0 \mapsto \emptyset, \quad q_2 \mapsto \emptyset, \quad q_{err} \mapsto \emptyset.$$

Above q_0 is not reachable because at the point when the program reaches location $\widehat{\mathbb{D}}$, at least one event must already have been emitted. q_1 is only reachable with event sequences that have at least one positive event and in the corresponding environments, x will be even, and pos will be equal to the most recent event value. Finally, there are also no event sequences that reach q_2 or q_{err} .

Abstract relations with the accumulator. Thus far we associate event sequence and environment pairs per control state, however, there are still infinite sets of pairs. We thus next abstract relations between the accumulator values at location q and the environments, employing a parametric abstract domain of base refinement types. That is, the type system provides abstractions of program values, which we can then also relate to abstractions of the accumulator. We will discuss

the formal details of this abstraction in Sec. 5 but illustrate the abstraction in the bottom of Fig. 1. For every location 1 and automaton state q_j , we compute a summary of the possible trace prefixes and corresponding abstraction of the program variables, accumulator, and relations between them. In this example, at the \mathbf{ev} pos location denoted p, our summary for $q_1^{\textcircled{p}}$ reflects the positive, monotonically increasing sequences and our summary for $q_2^{\textcircled{p}}$ reflects the negative, monotonically decreasing sequences. The automaton specifies if ever this is violated it will transition to q_{err} . The program is safe because at every location 1, we compute $q_{err}^{\textcircled{p}} \mapsto \bot$.

2.4 Type System, Inference, Evaluation

Our approach to verifying effects is fully automated. Toward achieving this, the rest of this paper addresses the challenges identified in Sec. 1, but here with more detail in the context of this example:

• Accumulative type and effect system (Sec. 4). In order to form relations between reachable automaton configurations' accumulator and program variables, we present a novel dependent type and effect system that is accumulative in nature. The type system allows us to, for example, express judgments on the (ev pos)[©] expression to ensure events are positive and monotonically increasingly. First, let φ_{acc}^{mono}(pos) be shorthand for pos = acc ∧ acc > 0, i.e., that the accumulator is equal to the program value of pos and that both are positive. Further, due to the recursive call, when we reach (ev pos)[©], we have that pos increases by one: pos → pos + 1. We thus obtain the following jugdment for (ev pos)[©]:

$$\begin{split} &\Gamma; [q_1 \mapsto \phi_{acc}^{mono}(\text{pos-1}), q_{err} \mapsto \bot, \ldots] \\ &\vdash \mathbf{ev} \; \text{pos} : () \& \left[\begin{array}{c} q_1 \mapsto \boxed{ \left[\phi_{acc}^{mono}(\text{pos-1}) \right] \odot \left[g : \text{pos} > \text{acc} \right]; \left[u : \text{acc} := \text{pos} \right]} \\ q_{err} \mapsto \bot, q_0 \mapsto \bot, q_2 \mapsto \bot \end{array} \right] \end{split}$$

We focus on the result of computing the \odot on the state q_1 to q_1 of the extended effect in the context of the judgment indicated by the boxed area. Note that the following sequence of entailments is valid: $guard \ \phi_{acc}^{mono}(pos-1) \implies pos-1=acc \implies g: pos>acc$. This means that the guard of the automaton transition from q_1 to q_1 must be satisfied by all the prefix traces in the context. The update of acc to pos reestablishes the $\phi_{acc}^{mono}(pos)$ at q_1 . None of the guards of the other outgoing transitions from q_1 are satisfied, thus other states map again to \bot . In summary, q_{err} remains unreachable.

- Effect abstract domain (Sec. 5). We formalize the effect abstract domain discussed above.
- Automated inference of effects (Sec. 6). We introduce a dataflow abstract interpretation inference of types that calculates summaries of effects, organized around concrete automaton control states, as seen in the example in Fig. 1. To achieve this, we exploit the parametricity of type systems (like [28]) over the kinds of constructs in the language, introducing sequences as a new base type. We then embed sequences into the q-indexed effect components.
- Verification, Implementation & Benchmarks (Sec. 7). To verify examples like temperature (and others among the 21 benchmarks), we have implemented our (i) abstract effect domain, (ii) accumulative type and effect system and (iii) automated inference in a new tool called evDrift. evDrift takes, as input, the program in an OCaml-like language (Fig. 1) as well as a symbolic accumulation automaton, written in a simple specification language (control states and the accumulator are integers and the automaton transition function is given by evDrift expressions). In Sec. 7 we discuss how our inference is used for verification, and implement the naïve product reductions to compare against tools for effect-free programs.

$$\begin{array}{lll} & & & & & & \\ & \text{E-APP} & & & & & \\ & \langle (\lambda x.e) \ v, \pi \rangle \rightarrow \langle e[v/x], \pi \rangle & & & \langle \bullet, \pi \cdot v \rangle & & \\ & & & & & \\ \end{array}$$

Fig. 2. Reduction rules of operational semantics.

• Evaluation (Sec. 8). evDrift verifies temperature in 35s, whereas previous assertion-verifiers (combined with our translations) either timeout (Drift) or run out of memory. More generally, evDrift verifies more examples and otherwise outperforms Drift 30.5× on benchmarks that both solve.

3 PRELIMINARIES

We briefly summarize background definitions and notation. The formal development of our approach uses an idealized language based on a lambda calculus:

$$e \in \mathcal{E} ::= c \mid x \mid \lambda x. e \mid (e e) \mid \mathbf{ev} \mid e$$

 $v \in \mathcal{V} ::= c \mid \lambda x. e$

Expressions e in the language consist of constant values $c \in Cons$ (e.g. integers and Booleans), variables $x \in Var$, function applications, lambda abstractions, and event expressions ev e_1 . We assume the existence of a dedicated unit value e e e0 e1. Values e2 e3 e4 consist of constants and lambda abstractions. We will often treat expressions as equal modulo alpha-renaming and write e3 e6 for the term obtained by substituting all free occurrences of e8 e9 with term e9 while avoiding variable capturing. We further write e1 for the set of free variables occurring in e2.

A value environment ρ is a total map from variables to values: $\rho \in Env \stackrel{\text{def}}{=} Var \rightarrow V$.

The operational semantics of the language is defined with respect to a transition relation over configurations $\langle e,\pi\rangle\in\mathcal{E}\times\mathcal{V}^*$ where e is a closed expression representing the continuation and π is a sequence of values representing the events that have been emitted so far. All configurations are considered initial and configurations $\langle v,\pi\rangle$ are terminal. To simplify the reduction rules, we use evaluation contexts E that specify evaluation order:

$$E ::= [] \mid E e \mid v E \mid ev E$$

The transition relation $\langle e, \pi \rangle \to \langle e', \pi' \rangle$ is then defined in Fig. 2. In particular, the rule E-EV captures the semantics of event expressions: the evaluation of **ev** v returns the unit value and its effect is to append the value v to the event sequence π . We write $\langle e, \pi \rangle \to \langle e', \pi' \rangle$ to mean that $\langle e, \pi \rangle \to^* \langle e', \pi' \rangle$ and there exists no $\langle e'', \pi'' \rangle$ such that $\langle e', \pi' \rangle \to \langle e'', \pi'' \rangle$.

(Non-accumulative) type and effect systems. Conventional type and effect systems [23] typically take the form $\Gamma \vdash e : \tau \& \phi$ and capture the local effects that occur during the evaluation of expression e to value v. Such systems have also been extended to the setting of higher-order programs [27, 34, 35]. While these systems are generally suitable to deductive reasoning, the judgements assume no information describing the program's behavior up to the evaluation of the respective expression. They thus fail to provide contextual reasoning for effects and so they suffer from a lack of precision and increase the difficulty of automation.

4 ACCUMULATIVE TYPE AND EFFECT SYSTEM

In this section, we present an abstract formalization of our dependent type and effect system for checking accumulative effect safety properties. The notion is parameterized by the notion of basic refinement types, which abstract sets of constant values, and the notion of dependent effects, which abstract sets of event sequences. Both abstractions take into account the environmental dependencies of values and events according to the context where they occur in the program. To facilitate the static inference of dependent types and effects, we formalize these parameters in terms of abstract domains in the style of abstract interpretation.

Base refinement types. We assume a lattice of base refinement types $\langle \mathcal{B}, \sqsubseteq^b, \bot^b, \sqcap^b, \sqcap^b \rangle$. Intuitively, a basic refinement type $\beta \in \mathcal{B}$ represents a set of pairs $\langle c, \rho \rangle$ where $c \in Cons$ and $\rho \in Env$ is a value environment capturing v's environmental dependencies. To formalize this intuition, we assume a concretization function $\gamma^b \in \mathcal{B} \to \wp(\mathcal{V} \times Env)$. We require that γ^b is monotone and top-strict (i.e., $\gamma^b(\top^b) = \mathcal{V} \times Env$).

We let $dom(\beta)$ denote the set of variables $x \in Var$ that are constrained by β . Formally:

$$dom(\beta) = \{ x \in Var \mid \exists v, \rho, \rho'. \langle v, \rho \rangle \in \gamma^b(\beta) \not\ni \langle v, \rho' \rangle \land \rho(x) \neq \rho'(x) \land \rho[x \mapsto \rho'(x)] = \rho'(x) \} .$$

Examples of possible choices for $\mathcal B$ include standard relational abstract domains such as octagons and polyhedra. For instance, when considering the polyhedra domain, basic refinement types can represent values subject to a system of linear constraints, such as the following, where ν refers to the value and x,y,z are the variables evaluated in the environments:

$$\beta = \{ v : \text{int} \mid x + y + z \le v \land x - y \le 0 \land y + z \le 2x \}$$
.

Dependent effects. Let $\langle \Phi, \sqsubseteq^{\phi}, \sqcup^{\phi}, \sqcup^{\phi}, \perp^{\phi} \rangle$ denote a lattice of dependent effects. Similar to basic refinement types, a dependent effect $\phi \in \Phi$ represents a set of pairs $\langle \pi, \rho \rangle$ where π is a trace and ρ captures its environmental dependencies. Again, we formalize this by assuming a monotone and top-strict function $\gamma^{\phi} \in \Phi \to \mathscr{P}(\mathcal{V}^* \times Env)$. Similar to basic types, we denote by $\operatorname{dom}(\phi)$ the set of variables that are constrained by ϕ . We assume some additional operations on our abstract domains for dependent types and effects that we will introduce below.

Types. With basic refinement types and dependent effects in place, we define our types as follows:

$$\tau \in \mathcal{T} ::= \beta \mid x : (\tau_2 \& \phi_2) \to \tau_1 \& \phi_1 \mid \exists x : \tau_1. \tau_2.$$

Intuitively, a function type $x:(\tau_2\&\phi_2)\to\tau_1\&\phi_1$ describes functions that take an input value x of type τ_2 and a prefix trace described by ϕ_2 such that evaluating the body e produces a result value of type τ_1 and extends the prefix trace to a trace described by ϕ_1 . Type refinements in τ_1 may depend on x. Existential types $\exists x:\tau_1.\tau_2$ represent values of type τ_2 that depend on the existence of a witness value x of type τ_1 .

We lift the function dom from basic types and effects to types in the expected way:

$$dom(x : (\tau_2 \& \phi_2) \to \tau_1 \& \phi_1) = dom(\tau_2) \cup ((dom(\phi_2) \cup dom(\tau_1) \cup dom(\phi_1)) \setminus \{x\})$$
$$dom(\exists x : \tau_1. \tau_2) = dom(\tau_1) \cup (dom(\tau_2) \setminus \{x\})$$

We also lift γ^b to a concretization function $\gamma^t \in \mathcal{T} \to \wp(\mathcal{V} \times \mathit{Env})$ on types:

$$\begin{split} & \gamma^{t}(\beta) = \gamma^{b}(\beta) \\ & \gamma^{t}(x: (\tau_{1} \& \phi_{1}) \to \tau_{2} \& \phi_{2}) = \mathcal{V} \times \textit{Env} \\ & \gamma^{t}(\exists x: \tau_{1}. \tau_{2}) = \{ \langle v, \rho \rangle \mid \langle v', \rho \rangle \in \gamma^{t}(\tau_{1}) \land \langle v, \rho[x \mapsto v'] \rangle \in \gamma^{t}(\tau_{2}) \} \ . \end{split}$$

Note that the function γ^t uses a coarse approximation of function values. The reason is that we will use γ^t to give meaning to typing environments, which we will in turn use to define what it means to strengthen a type with respect to dependencies expressed by a given typing environment. When

strengthening with respect to a typing environment, we will only track dependencies to values of base types, but not function types.

We define typing environments Γ as binding lists between variables and types: $\Gamma := \emptyset \mid \Gamma, x : \tau$. We extend dom to typing environments as follows:

$$dom(\emptyset) = \emptyset$$
 $dom(\Gamma, x : \tau) = dom(\Gamma) \cup \{x\}$.

We then impose a well-formedness condition $wf(\Gamma)$ on typing environments. Intuitively, the condition states that bindings in Γ do not constrain variables that are outside of the scope of the preceding bindings in Γ :

If $wf(\Gamma)$ and $x \in dom(\Gamma)$, then we write $\Gamma(x)$ for the unique type bound to x in Γ .

As previously mentioned, we lift y^t to a concretization function for typing environments:

$$\gamma^{t}(\emptyset) = Env \qquad \gamma^{t}(\Gamma, x : \tau) = \gamma^{t}(\Gamma) \cap \{ \rho \mid \exists v. \langle v, \rho \rangle \in \gamma^{t}(\Gamma(x)) \} .$$

Typing judgements. Our type system builds on existing refinement type systems with semantic subtyping [5, 18]. Subtyping judgements take the form $\Gamma \vdash \tau_1 <: \tau_2$ and are defined by the rules in Fig. 3. We implicitly restrict these judgments to well-formed typing environments.

The rule S-BASE handles subtyping on basic types by reducing it to the ordering \sqsubseteq^b . Importantly, the basic type β_1 on the left side is strengthened with the environmental dependencies expressed by Γ . To this end, we assume the existence of an operator $\beta[\Gamma]$ that satisfies the following specification:

$$\gamma^b(\beta[\Gamma]) \supseteq \gamma^b(\beta) \cap (\mathcal{V} \times \gamma^{\mathsf{t}}(\Gamma))$$
.

We require this operator to be monotone in both arguments where $\Gamma \leq \Gamma'$ iff for all $x \in \text{dom}(\Gamma')$, $\Gamma(x) = \Gamma'(x)$. We also assume a strengthening operator $\phi[\Gamma]$ on effects with corresponding assumptions.

The rule s-fun handles subtyping of function types. As expected, the input type and effect are ordered contravariantly and the output type and effect covariantly. Note that we allow the input effect to depend on the parameter x.

The rule s-exists introduces existential types on the left side of the subtyping relation whereas s-wit introduces them on the right side. The latter rule relies on an operator $\tau[y/x]$ that expresses substitution of the dependent variable x in type τ by the variable y. This operator is defined by lifting corresponding substitution operators $\beta[y/x]$ on basic types and $\phi[y/x]$ on effects in the expected way. The soundness of these operators is captured by the following assumption:

$$\gamma^{b}(\beta[y/x]) \supseteq \{ \langle v, \rho[x \mapsto \rho(y)] \rangle \mid \langle v, \rho \rangle \in \gamma^{b}(\beta) \}$$
$$\gamma^{\phi}(\phi[y/x]) \supseteq \{ \langle \pi, \rho[x \mapsto \rho(y)] \rangle \mid \langle \pi, \rho \rangle \in \gamma^{\phi}(\phi) \} .$$

Typing judgments take the form Γ ; $\phi \vdash e : \tau \& \phi'$ and are defined by the rules in Fig. 4. Intuitively, such a judgment states that under typing environment Γ , expression e extends the event sequences described by effect ϕ to the event sequences described by effect ϕ' and upon termination, produces a value described by type τ . Again, the typing environments occurring in typing judgments are implicitly restricted to be well-formed. Moreover, we implicitly require $\operatorname{dom}(\phi) \subseteq \operatorname{dom}(\Gamma)$.

The rule T-CONST is used to type primitive values. For this, we assume an operator that maps a primitive value c to a basic type $\{v = c\} \in \mathcal{B}$ such that $\gamma^b(\{v = c\}) \supseteq \{c\} \times Env$.

Fig. 3. Semantic subtype relation.

T-const
$$\Gamma_{\text{T-VAR}} = \Gamma_{\text{T-VAR}} = \Gamma_{\text{T-EV}} \frac{\Gamma \ ; \ \phi \vdash e : \tau \& \phi'}{\Gamma; \phi \vdash c : \{v = e\} \& \phi} = \Gamma_{\text{T-EV}} \frac{\Gamma \ ; \ \phi \vdash e : \tau \& \phi'}{\Gamma; \phi \vdash e : \tau \& \phi} = \frac{\Gamma, x : \tau_2 \ ; \ \phi_2 \vdash e : \tau_1 \& \phi_1}{\Gamma; \phi \vdash \lambda x.e : (x : \tau_2 \& \phi_2 \longrightarrow \tau_1 \& \phi_1) \& \phi} = \frac{\Gamma, \phi \vdash e_1 : \tau_1 \& \phi_1}{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi_1} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi_1}{\Gamma; \phi \vdash e_1 : \epsilon_2 : \exists x : \tau_2. (\tau \& \phi')} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi_1}{\Gamma; \phi \vdash e_1 : \tau_2 \& \phi_2} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'}{\Gamma; \phi \vdash e_1 : \tau_2 \& \phi'} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'}{\Gamma; \phi \vdash e_1 : \tau_2 \& \phi'} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'}{\Gamma; \phi \vdash e_1 : \tau_2 \& \phi'} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'}{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'}{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'}{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'}{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'}{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'}{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'}{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'}{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'}{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'}{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'}{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'}{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'}{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'}{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'}{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'}{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'}{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'}{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'}{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'}{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'}{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'}{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'}{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'}{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'}{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'}{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'}{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'}{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'}{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi'} = \frac{\Gamma; \phi \vdash e_1 : \tau_1 \& \phi$$

Fig. 4. Typing relation.

The rule T-EV is used to type event expressions **ev** e. For this, we assume an *effect extension operator* $\phi \odot \tau$ that abstracts the extension of the traces represented by effect ϕ with the values represented by the type τ , synchronized on the value environment:

$$\gamma^\phi(\phi\odot\tau)\ \supseteq\ \{\langle\pi\cdot v,\rho\rangle\mid \langle v,\rho\rangle\in\gamma^{\rm t}(\tau)\wedge\langle\pi,\rho\rangle\in\gamma^\phi(\phi)\}\ .$$

We require that \odot is monotone in both of its arguments. The following is an example judgment for the **ev** (*pos* + 1) expression in the temperature example from Sec. 2:

$$\Gamma$$
, $pos: \tau$; $[..q_1 \mapsto acc = pos > 0] \vdash ev (pos + 1) : (unit&[..q_1 \mapsto acc = pos + 1 > 0])$

The effect to the left of the turnstile describes event prefixes associated with all executions leading to the evaluation of expression **ev** (pos + 1). It states that q_1 is the only reachable state and the accumulator is equal to variable pos. Given that pos has the base type $\tau = \{v \mid v > 0\}$, we can derive that (pos+1) has type $\tau' = \{v \mid v = pos+1\}$. The typing judgement states that for all executions the extended effect that accounts for the concatenated values represented by τ' preserves the invariant between the variable representing observable events at that location and the accumulator. When effects are drawn from the SAA-based abstract domain, the symbolic guard [acc < pos + 1] must be satisfied before updating the accumulator to the new symbolic value (pos + 1) of the event.

The notation $\exists x : \tau. (\tau' \& \phi)$ used in the conclusion of rules T-APP and T-CUT is a shorthand for $(\exists x : \tau. \tau') \& (\exists x : \tau. \phi)$, where $\exists x : \tau. \phi$ computes the projection of the dependent variable x in effect ϕ , subject to the constraints captured by type τ . That is, this operator must satisfy:

$$\gamma^{\phi}(\exists x : \tau. \phi) \supseteq \{ \langle \pi, \rho[x \mapsto v] \rangle \mid \langle \pi, \rho \rangle \in \gamma^{\phi}(\phi[x : \tau]) \} .$$

As with our other abstract domain operators, we require this to be monotone in both τ and ϕ .

The rule T-CUT allows one to introduce an existential type $\exists x : \tau. \tau'$, provided one can show the existence of a witness value v of type τ' for x. In other dependent refinement type systems, this rule is replaced by a variant of rule s-WIT as part of the rules defining the subtyping relation. We use the alternative formulation to avoid mutual recursion between the subtyping and typing rules.

The remaining rules are as expected. In particular, the rule T-WEAKEN allows one to weaken a typing judgement using the subtyping relation (and ordering on effects), relative to the given typing environment.

Soundness. We prove the following soundness theorem. Intuitively, the theorem states that (1) well-typed programs do not get stuck and (2) the output effect established by the typing judgement approximates the set of event traces that the program's evaluation may generate.

Theorem 4.1 (Soundness). If $\phi \vdash e : \tau \& \phi'$ and $\langle \pi, \rho \rangle \in \gamma^{\phi}(\phi)$, then $\langle e, \pi \rangle \leadsto \langle e', \pi' \rangle$ implies $e' \in \mathcal{V}$ and $\langle \pi', \rho \rangle \in \gamma^{\phi}(\phi')$.

The soundness proof details are available in Apx. A, but we summarize here. The proof of Theorem 4.1 proceeds in two steps. We first show that any derivation of a typing judgement $\phi \vdash e : \tau \& \phi'$ can be replayed in a concretized version of the type system where basic types are drawn from the concrete domain $\wp(\mathcal{V} \times Env)$ (i.e., both γ^b and γ^ϕ are the identity on their respective domain). Importantly, in this concretized type system all operations such as strengthening $\tau[\Gamma]$ and effect extension $\phi \odot \tau$ are defined to be precise. That is, we have e.g. $\phi \odot \tau \stackrel{\text{def}}{=} \{\langle \pi \cdot v, \rho \rangle \mid \langle v, \rho \rangle \in \tau \wedge \langle \pi, \rho \rangle \in \phi \}$. In a second step, we then show standard progress and preservation properties for the concretized type system.

While one could prove progress and preservation directly for the abstract type system, this would require stronger assumptions on the abstract domain operations. By first lowering the abstract typing derivations to the concrete level, the rather weak assumptions above suffice.

5 AUTOMATA-BASED DEPENDENT EFFECTS DOMAIN

In this section, we introduce an automata-based dependent effects domain Φ_A . The domain is parametric in an automaton A that specifies the property to be verified for a given program. That is, the dependent effects domain is design to support solving the following verification problem: given a program, show that the prefixes of the traces generated by the program are disjoint from the language recognized by A. To this end, the abstract domain tracks the reachable states of the automaton: each time the program emits an event, A advances its state according to its transition relation. The set of automata states is in general infinite, so we abstract A's transition relation by abstract interpretation. The abstraction takes into account the program environment at the point where the event is emitted, thus, yielding a domain of dependent effects.

5.1 Symbolic Accumulator Automata

Our automaton model is loosely inspired by the various notions of (symbolic) register or memory automata considered in the literature [3, 7, 16]. A *symbolic accumulator automaton (SAA)* is defined over a potentially infinite alphabet and a potentially infinite data domain. In the following, we will fix both of these sets to coincide with the set of primitive values \mathcal{V} of our object language. Formally,

an SAA is a tuple $A = \langle Q, \Delta, \langle q_0, a_0 \rangle, F \rangle$. We specify the components of the tuple on-the-fly as we define the semantics of the automaton.

A state $\langle q,a\rangle$ of A consists of a control location q drawn from the finite set Q and a value $a\in \mathcal{V}$ that indicates the current value of the accumulator register. The pair $\langle q_0,a_0\rangle$ with $q_0\in Q$ and $a_0\in \mathcal{V}$ specifies the initial state of A. The set $F\subseteq Q$ is the set of final control locations.

The symbolic transition relation Δ denotes a set of transitions $\langle q,a\rangle \stackrel{v}{\to} \langle q',a'\rangle$ that take a state $\langle q,a\rangle$ to a successor state $\langle q',a'\rangle$ under input symbol $v\in\mathcal{V}$. The transitions are specified as a finite set of symbolic transitions $\langle q,g,u,q'\rangle\in\Delta$, written $q\stackrel{\{g\}u}{\longrightarrow} q'$, where $g\in\mathcal{G}$ is a guard and $u\in\mathcal{U}$ an (accumulator) update. Both guards and updates can depend on the input symbol v consumed by the transition and the accumulator value a in the pre state, allowing the automaton to capture non-regular properties and complex program variable dependencies. We make our formalization parametric in the choice of the languages that define the sets \mathcal{G} and \mathcal{U} . To this end, we assume denotation functions $[\![g]\!](v,a)\in\mathbb{B}$ and $[\![u]\!](v,a)\in\mathcal{V}$ that evaluate a guard g to its truth value, respectively, an update u to the new accumulator value. We then have $\langle q,a\rangle \stackrel{v}{\to} \langle q',a'\rangle$ if there exists $q\stackrel{\{g\}u}{\longrightarrow} q'\in\Delta$ such that $[\![g]\!](v,a)=$ true and $[\![u]\!](v,a)=a'$. We require that Δ is such that this transition relation is total. For $\pi\in\mathcal{V}^*$, we denote by $\langle q,a\rangle \stackrel{\pi}{\to} {}^*\langle q',a'\rangle$ the reflexive transitive closure of this relation and define the semantics of a state as the set of traces that reach that state:

$$[\![\langle q, a \rangle]\!] = \{ \pi \mid \langle q_0, a_0 \rangle \xrightarrow{\pi} {}^* \langle q, a \rangle \} .$$

With this, the language of *A* is defined as

$$\mathcal{L}(A) = \left[\ \left| \left\{ \left[\left\langle q, a \right\rangle \right] \right| \mid q \in F \right. \right\} \right.$$

Intuitively, $\mathcal{L}(A)$ is the set of all bad prefixes of event traces that the program is supposed to avoid.

5.2 Automata-based Dependent Effects Domain

We now define the domain Φ_A . For the remainder of this section, we fix an SAA A and omit the subscript A for Φ_A and all its operations.

Concrete automata domain of dependent effects. Recall from Section 4 that a dependent effect domain Φ represents a sublattice of $\wp(\mathcal{V}^* \times Env)$. Since the states of A represents sets of event traces, a natural first step to define such a sublattice is to pair off automaton states with value environments: $\Phi_C = \wp(Q \times \mathcal{V} \times Env)$.

The corresponding concretization function $\gamma_C^{\phi}: \Phi_C \to \wp(\mathcal{V} \times \rho)$ is given by:

$$\gamma_C^\phi(\phi_C) = \bigcup_{\langle q,a,\rho\rangle\in\phi_C} \{\,\langle \pi,\rho\rangle\mid \pi\in [\![\langle q,a\rangle]\!]\,\}\ .$$

Since γ_C^{ϕ} is defined element-wise on Φ_C , it is easy to see that it is monotone and preserves arbitrary meets. It is therefore the upper adjoint of a Galois connection between $\wp(\mathcal{V}^* \times \mathit{Env})$ and Φ_C . Let α_C^{ϕ} be the corresponding lower adjoint, which is uniquely determined by γ_C^{ϕ} .

The operations on the dependent effect domain Φ_C are then obtained calculationally as the best abstractions of their concrete counterparts. In particular, we define:

$$\begin{split} \phi_C \odot_C \beta &= \alpha_C^{\phi}(\{\langle \pi \cdot v, \rho \rangle \mid \langle v, \rho \rangle \in \gamma^b(\beta) \land \langle \pi, \rho \rangle \in \gamma_C^{\phi}(\phi_C) \}) \\ &= \{\langle q', a', \rho \rangle \mid \exists \langle v, \rho \rangle \in \gamma^b(\beta), \langle q, a, \rho \rangle \in S. \langle q, a \rangle \xrightarrow{v} \langle q', a' \rangle \} \end{split}$$

The characterization of \bigcirc_C relies on the fact that the transition relation of the automaton is total. Note that the soundness condition on \bigcirc_C imposed in Section 4 is obtained by construction from

the properties of Galois connections:

$$\gamma_C^\phi(\phi_C\odot_C\beta)\supseteq\{\,\langle\pi\cdot v,\rho\rangle\mid\langle v,\rho\rangle\in\gamma^b(\beta)\wedge\langle\pi,\rho\rangle\in\gamma_C^\phi(\phi_C)\,\}\ .$$

The remaining operations $\phi[\Gamma]$, $\phi_C[y/x]$, and $\exists x : \tau. \phi_C$ are obtained accordingly.

Abstract automata domain of dependent effects. Since the elements $S \in \Phi_C$ can be infinite sets, the operations on Φ_C such as \odot_C are typically not computable. We therefore layer further abstractions on top of Φ_C to obtain an abstract automata domain of dependent effects with computable operations.

We proceed in two steps. Firstly, we change the representation of our abstract domain elements by partitioning the elements of each $\phi_C \in \Phi_C$ based on the control location of the automaton state. That is, we switch to the effect domain $\Phi_R = Q \rightarrow \wp(\mathcal{V} \times Env)$, ordered by pointwise subset inclusion. The corresponding concretization function $\gamma_R^\phi \in \Phi_R \to \Phi_C$ is given by

$$\gamma_R^{\phi}(\phi_R) = \{ \langle q, a, \rho \rangle \mid \langle a, \rho \rangle \in \phi_R(q) \}$$
.

Clearly, we do not lose precision when changing the representation of the elements $\phi_C \in \Phi_C$ to elements of Φ_R . In fact, γ_R^{ϕ} is a lattice isomorphism. Its inverse $\alpha_R^{\phi} = \gamma_R^{\phi^{-1}}$ is the lower adjoint of a Galois connection between Φ_C and Φ_R .

As before, we obtain the abstract domain operations on Φ_R by defining them as the best abstractions of their counterparts on Φ_C . In particular, we define

$$\phi_R \odot_R \beta = \alpha_R^\phi(\gamma_R^\phi(\phi_R) \odot_C \beta) = \lambda q'. \left\{ \left\langle a', \rho \right\rangle \mid \exists q', \left\langle v, \rho \right\rangle \in \gamma^b(\beta), \left\langle a, \rho \right\rangle \in \phi_R(q). \left\langle q, a \right\rangle \xrightarrow{v} \left\langle q', a' \right\rangle \right\} \ .$$

Now consider again our abstract domain of base refinement types $\langle \mathcal{B}, \sqsubseteq^b, \bot^b, \top^b, \sqcup^b, \sqcap^b \rangle$ that we have assumed as a parameter of the type and effects system of Section 4. Recall that each element $\beta \in \mathcal{B}$ abstracts a relation between values and value environments: $\gamma^b(\beta) \subseteq \wp(\mathcal{V} \times Env)$. We can thus reuse this domain to abstract the relations $\phi_R(q) \subseteq \wp(\mathcal{V} \times Env)$ between the reachable accumulator values at location *q* of the automaton and the environments. This leads to the following definition of our final automata-based effect domain: $\Phi = Q \to \mathcal{B}$. The accompanying concretization function $\gamma_{\mathcal{B}}^{\phi} \in \Phi \to \Phi_R$ is naturally obtained by pointwise lifting of $\gamma^b : \gamma_{\mathcal{B}}^{\phi}(\phi) = \gamma^b \circ \phi$. The overall concretization function $\gamma^\phi : \Phi \to \wp(\mathcal{V}^* \times \mathit{Env})$ is defined by composition of the intermediate concretization functions: $\gamma^{\phi} = \gamma_{C}^{\phi} \circ \gamma_{R}^{\phi} \circ \gamma_{\mathcal{B}}^{\phi}$. We then define the operations on Φ in terms of the operations on \mathcal{B} . Again, we focus on the

operator \odot . The remaining operations are defined similarly.

Our goal is to ensure that the overall soundness condition on ⊙ is satisfied. We achieve this by defining $\phi \odot \beta$ such that

$$\gamma_{\mathcal{B}}^{\phi}(\phi \odot \beta) \supseteq \gamma_{\mathcal{B}}^{\phi}(\phi) \odot_{R} \beta . \tag{1}$$

Assuming (1) the overall soundness of ⊙ then follows by construction:

Lemma 5.1. For all
$$\phi \in \Phi$$
 and $\beta \in \mathcal{B}$, $\gamma^{\phi}(\phi \odot \beta) \supseteq \{\langle \pi \cdot v, \rho \rangle \mid \langle v, \rho \rangle \in \gamma^{t}(\beta) \land \langle \pi, \rho \rangle \in \gamma^{\phi}(\phi)\}$.

Let us thus define an appropriate \odot that satisfies (1). To this end, we first expand $\gamma_{\mathcal{B}}^{\phi}(\phi) \odot_{\mathcal{R}} \beta$:

$$\begin{split} & \gamma^{\phi}_{\mathcal{B}}(\phi) \odot_{R} \beta \\ &= \lambda q'. \left\{ \left\langle a', \rho \right\rangle \mid \exists q', \left\langle v, \rho \right\rangle \in \gamma^{b}(\beta), \left\langle a, \rho \right\rangle \in \gamma^{b}(\phi(q)). \left\langle q, a \right\rangle \xrightarrow{v} \left\langle q', a' \right\rangle \right\} \\ &= \lambda q'. \bigcup_{\substack{\{\langle a', \rho \rangle \mid \exists \langle v, \rho \rangle \in \gamma^{b}(\beta), \left\langle a, \rho \right\rangle \in \gamma^{b}(\phi(q)). \left[\!\left[g \right]\!\right] (v, a) = \mathsf{true} \wedge \left[\!\left[u \right]\!\right] (v, a) = a' \right\} \ . \end{split}$$

The last equation suggests that we can compute $\phi \odot \beta$ by abstracting for each q', each symbolic transition $q \xrightarrow{\{g\}u} q' \in \Delta$ of the automaton separately, and then take the join of the results. In order to abstract a symbolic transition, we need appropriate abstractions of the semantics of guards and updates with respect to base refinement types. For the sake of our formalization, we therefore assume an abstract interpreter $\llbracket \cdot \rrbracket^{\#} : (\mathcal{G} \cup \mathcal{U}) \to \mathcal{B} \times \mathcal{B} \to \mathcal{B}$ such that for all $t \in \mathcal{G} \cup \mathcal{U}$ and $\beta, \beta' \in \mathcal{B}$

$$\gamma^b(\llbracket t \rrbracket^\#(\beta,\beta')) \supseteq \{\, \langle v',\rho \rangle \mid \exists v,a.\, \langle v,\rho \rangle \in \gamma^b(\beta) \, \land \, \langle a,\rho \rangle \in \gamma^b(\beta') \, \land \, v' = \llbracket t \rrbracket(v,a) \, \} \ .$$

We then derive $\phi \odot \beta$ from the above equation as follows:

$$\phi \odot \beta = \lambda q'. \bigsqcup_{q \xrightarrow{\{g\}u} q' \in \Delta} \{ \left[\!\left[u\right]\!\right]^{\!\#} (\beta \sqcap \beta_g, \phi(q) \sqcap \beta_g) \mid \beta_g = (\exists \nu. \left[\!\left[g\right]\!\right]^{\!\#} (\beta, \phi(q)) \sqcap \{\nu = \mathsf{true}\}) \, \} \ .$$

Here, β_g captures the environments ρ shared by β and $\phi(q)$ for which the guard g evaluates to true. It is used to strengthen β and $\phi(q)$ when evaluating the update expression u. We here assume that \mathcal{B} provides an operator $\exists v.\beta$ that projects out the value component of the pairs represented by some $\beta \in \mathcal{B}$. That is, we must have:

$$\gamma^b(\exists v. \beta) = \{ \langle v, \rho \rangle \mid \exists v'. \langle v', \rho \rangle \in \gamma^b(\beta) \}.$$

The fact that \odot indeed satisfies (1) then follows from the assumption on the abstract interpreter for guards and expressions as well as the soundness of the abstract domain operations of \mathcal{B} .

Lemma 5.2. For all
$$\phi \in \Phi$$
 and $\beta \in \mathcal{B}$, $\gamma_{\mathcal{B}}^{\phi}(\phi \odot \beta) \supseteq \gamma_{\mathcal{B}}^{\phi}(\phi) \odot_{R} \beta$.

Similarly, monotonicity of \odot follows immediately from the monotonicity of the operations on \mathcal{B} .

The remaining operators on Φ assumed in Section 4 (i.e., $\phi[\Gamma]$, $\phi[y/x]$, and $\exists x : \tau. \phi$) are obtained directly by a pointwise lifting of the corresponding operators on \mathcal{B} .

6 DATA FLOW INFERENCE OF TYPES AND EFFECTS

We present now an inference algorithm for the dependent type and effect system. To facilitate the calculation of precise effects we build upon the existing data flow refinement type inference algorithm [28] based on abstract interpretation. We proceed first by translating the program into a language where expressions \mathbf{ev} e are absent. Within this language, the prefix event traces π are encoded as event sequence values and are symbolically represented at the syntactic level. The procedure translates every expression e so that it produces a pair consisting of the value and event sequence obtained from evaluating e, effectively monadifying the effectful computation. By instantiating the type inference algorithm such that the refinement types for the event sequence terms are drawn from our novel effect abstract domain, we obtain types that correspond to effects in our type and effect system. Lastly, we establish a soundness theorem, proving that a typing derivation for the dependent types and effects system can be inferred from a typing derivation for the translated program.

Contrast to naïve product translation. The soundness argument follows a translation argument. Thus a keen reader may notice some conceptual similarities between the naïve product translation and the translation discussed in this section. We emphasize that these are absolutely not the same thing for a few reasons. First, we can take advantage of the fact that the abstract interpreter can be specialized to only analyze translated programs. That is, our abstract interpretation method here performs the translation *implicity* during its analysis of the (untranslated) program. As such it can fuse together what would otherwise be costly joins and projections needed for analysis

of the naïve product. Second, the automaton transition function is not embedded directly in the program. Instead, the sequence concatenation operator is interpreted by the abstract effect domain. Finally, the abstract domain is organized around the concrete automaton states, providing direct disjunctivity in the abstract domain rather than requiring the abstract interpreter to have some other means of disjunctive reasoning.

6.1 Background: Dataflow inference for effect-free programs

Data flow type inference, as described by [28], employs a calculational approach in an abstract interpretation style to iteratively compute a dependent refinement type for every subexpression of a program. The corresponding inference algorithm is implemented in the Drift tool. The typing produced by the algorithm yields a valid typing derivation in a dependent refinement type system, which we refer to as the Drift type system and denote with superscript d's, e.g. Γ^d , in the following.

The details of the inference algorithm itself are of no import for the present paper. What is relevant is that the algorithm is parametric in the choice of an abstract domain of basic types \mathcal{B} , which coincides with our parametrization of the types and effect system as well as the supported primitive operations on values represented by these basic types (e.g., arithmetic operations, etc.).

A challenge in connecting the type inference result with our type and effects system is that the inference algorithm has been proven sound with respect to a bespoke dataflow semantics of functional program rather than a standard operational semantics like the one underlying our system. To bridge this gap, we relate the two type systems at the abstract level by showing that, from the typing derivation for a translated program produced by the soundness proof of [28], one can reconstruct a typing derivation in the types and effects system for the original effectful program. The overall soundness then follows from Theorem 4.1.

Rather than describing the inference algorithm in detail, we can therefore focus on the instantiation of the Drift type system with the relevant primitive operations needed in our translation. Apart from not supporting effects directly, the Drift type system slightly deviates from ours in the handling of subtyping because it is designed to characterize the fixpoints of the abstract interpretation.

6.2 Dataflow refinement type system with event sequences as program values

In our instantiation of the Drift type system, we treat event sequences as values that can be manipulated directly by the program. The only primitive operator defined on event sequences is $e_1 \cdot e_2$ where e_1 is expected to evaluate to an event sequence π_1 and e_2 to a value v_2 . The result of the operation is the concatenated event sequence $\pi_1 \cdot v_2$. We additionally have the constant expression ϵ denoting the empty event sequence. We also have a built-in pair constructor $\langle e_1, e_2 \rangle$ and projection operators $\#_1(e)$ and $\#_2(e)$ on pairs. The instantiated Drift types are then:

$$t ::= \perp^d \mid \top^d \mid \beta \mid \phi \mid x : t_1 \to t_2 \mid t_1 \times t_2 .$$

The types \top^d and \bot^d are the extrema of the type lattice. \top^d can be thought of as representing a type error and \bot^d represents the empty set of values, indicating that evaluation of an expression never returns, respectively, that the expression is unreachable in the program. β is an element of \mathcal{B} , ϕ is an element of Φ , $x:t_1\to t_2$ is a dependent function type and $t_1\times t_2$ a pair type.

The instantiated type system is then given by the subtyping and typing rules in Fig. 5^2 . It comes equipped with type operations t[x=y], $t[\Gamma^d]$ that strengthen a type t with constraints corresponding to the equality between two variables, and the typing environment respectively. These

 $[\]overline{^2}$ The rules of the original type system in [28] are more involved as they allow for context-sensitive analysis of function calls. We here present a simplified instantiation of the rules with no context-sensitivity.

Fig. 5. Data flow refinement type system

$$\mathcal{T}\llbracket c \rrbracket(\varnothing) \stackrel{\mathrm{def}}{=} \langle c, \varnothing \rangle \qquad \mathcal{T}\llbracket x \rrbracket(\varnothing) \stackrel{\mathrm{def}}{=} \langle x, \varnothing \rangle \qquad \mathcal{T}\llbracket \lambda x. \, e \rrbracket(\varnothing) \stackrel{\mathrm{def}}{=} \langle \lambda x. \lambda y. (\mathcal{T}\llbracket e \rrbracket(y)), \, \varnothing \rangle$$

$$\mathcal{T}\llbracket e_1 \, e_2 \rrbracket(\varnothing) \stackrel{\mathrm{def}}{=} \qquad \qquad \mathcal{T}\llbracket \mathbf{ev} \, e \rrbracket(\varnothing) \stackrel{\mathrm{def}}{=} \qquad \qquad \mathcal$$

(a) Forward term tranformation

$$\ddot{\overline{\mathcal{T}}}^t(\bot^d) \stackrel{\text{def}}{=} \bot^b \quad \ddot{\overline{\mathcal{T}}}^t(\top^d) \stackrel{\text{def}}{=} \top^b \quad \ddot{\overline{\mathcal{T}}}^t(\beta) \stackrel{\text{def}}{=} \beta$$

$$\ddot{\overline{\mathcal{T}}}^t((x:t_x) \to (\varnothing_x:\phi_x) \to t)) \stackrel{\text{def}}{=} x: \ddot{\overline{\mathcal{T}}}^t(t_x) \& \phi_x \to \ddot{\overline{\mathcal{T}}}^{te}(t) \qquad \qquad \ddot{\overline{\mathcal{T}}}^{te}(\langle t,\phi \rangle) \stackrel{\text{def}}{=} \ddot{\overline{\mathcal{T}}}^t(t) \& \phi$$

(b) Backward type and type/effect translation

Fig. 6. Tuple-encoding-based translation

operators are defined similarly for base types to the strengthening operator $\beta[\Gamma]$ in our type and effect system, the latter operator recursively pushes the strengthening of compound types to each constituent type. The type constructor $[\nu = c]^d$ returns a type abstracting constant value c.

Next we will describe how to translate programs with effects into monadified programs without effects. This then allows us to instantiate the inference algorithm to infer effect summaries.

6.3 Translation from effectful programs to programs with sequences

Figure 6a defines the translation function from effectful programs into a functional language where **ev** expressions are absent. This function preserves the operational semantics while ensuring that the events emitted during the program's execution are carried through the computation.

The translation functions $\mathcal{T}[e](\varpi)$ take two arguments: the effectful expression e in the source language and an expression ϖ in the target language that evaluates to the effect prefix produced by the context of e. The transformation follows the call-by-value, left-to-right evaluation order of source language's operational semantics. For constant c and variable x expressions, we pair them with the event prefix observed up to the current evaluation context. Lambda abstractions λx . e go through a syntactic transformation and are then paired with the event prefix in the evaluation environment. The translated function expressions expects an additional parameter y representing the event prefix observed at the call site. Then, as expected, the translation of the function body considers y as the new event prefix. Thus, a translated function always returns a pair, where the second component represents the event sequence produced after evaluation of a function call. The translation of application terms $\mathcal{T}[e_1 \ e_2](\varnothing)$ ensures the strict-evaluation semantics for our source language. We here abbreviate the sequence of let bindings, i.e., let x = e in let $x_1 = e$ $\#_1 x$ in let $x_1 = \#_2 x$ in e', with let $\langle x_1, x_2 \rangle = \#_{1,2} e$ in e'. The last expression we consider is the event expression. Translation $\mathcal{T}[\mathbf{e}\mathbf{v}\ e](\varpi)$ follows the order of evaluation by first converting e in the context of the current event prefix and then capturing the event sequence y associated with its result value x. The result is the pair consisting of the unit value and the extended event sequence $y \cdot x$.

6.4 Soundness

We prove the theorem that inference of type and effect via program translation is sound. Intuitively, the theorem states that if we can obtain a Drift typing derivation for a translated term, then we can construct a derivation for the typing judgment in the type and effects systems. The construction uses backward translation functions $\bar{\mathcal{T}}^t$ and $\bar{\mathcal{T}}^{te}$, defined in Fig. 6b, that embed types in the translated program back to types and type/effect pairs, respectively.

Theorem 6.1. If
$$\Gamma^d, y : \phi \vdash^d \mathcal{T}[\![e]\!](y) : t$$
, then $\dot{\overline{\mathcal{T}}}^t(\Gamma^d); \phi \vdash e : \dot{\overline{\mathcal{T}}}^{te}(t)$.

The proof of Theorem 6.1 builds on the structure of the translated program and relates backward translatable typing environments and types. We start by showing that base refinement types have the same type semantics, and that strengthening a base type with respect to the typing environment in the target type system gives us a semantically equal type after strengthening with backward translated typing environment in the type and effects system. Then we show that if we have a Drift subtyping derivation for backward translatable types and typing environments, $t[\Gamma^d] <: d t'[\Gamma^d]$, then we can obtain a subtyping derivation $\tilde{\mathcal{T}}^t(\Gamma^d) \vdash \tilde{\mathcal{T}}^t(t) <: \tilde{\mathcal{T}}^t(t')$ in the type and effects system. The proof (Apx. B) proceeds by structural induction on the source expression e.

7 VERIFICATION, IMPLEMENTATION, BENCHMARKS

7.1 Verification algorithms

As discussed in Sec. 2, our abstract effect domain seeks to improve over a naïve approach of translating (via tuples or CPS) an input program/property of effects into an effect-free product program that carries its effect trace and employs existing assertion checking techniques. In order to evaluate whether there is an improvement, we now summarize these two verification algorithms and their implementations.

(1) *Verification via translation to effect-free assertions*. As discussed in Sec. 6, the input program and property are syntactically translated into an effect-free program. One can then apply, for example, a higher-order type inference algorithm such as Pavlinovic et al. [28] and the DRIFT tool.

The principal theoretical shortcoming of this algorithm is that it places a substantial burden on the type system (or other verification strategy) to track effect sequences as program values that flow from each (translated) event expression to the next. In this strategy, where an **ev** *e* expression occurred in the original input program, the translated program has an event prefix variable (and accumulator variable) and constructs an extended event sequence. Unfortunately, today's higher-order program verifiers do not have good methods for summarizing program value sequences, nor do they exploit the automaton structure to organize possible sequence values. Thus, those tools struggle to validate the later **assert**ions.

(2) Verification through the effect domain. Our key contribution is based on the effect abstract domain (Sec. 5) and dataflow type & effect inference algorithm (Sec. 6). It is straight-forward to construct a verification algorithm on top of these new principals. One merely has to ensure that at every program location $\widehat{\mathbb{Q}}$, the computed summary associates \bot with every error state $q_{err}^{\widehat{\mathbb{Q}}}$.

Our organization of event prefixes around concrete automaton states allows us to better summarize those prefixes into categories, and can be thought of as a control-state-wise disjunctive partitioning. Thus, at each ev e expression, the (dataflow) type system directly updates each q's summary with the next event.

Sec. 8 experimentally evaluates both of these algorithms and compares them.

7.2 Implementation Details

We implemented both of the above verification algorithms in a prototype tool called **ev**Drift, as an extension to the Drift [28] type inference tool, which builds on top of the Apron library [15] to support various numerical abstract domains of type refinements.

evDrift takes programs written in a subset of OCaml along with an automaton property specification file as input. **ev**Drift supports higher-order recursive functions, operations on primitive types such as integers and booleans, as well as a non-deterministic if-then-else branching operator. The property specification lists the set of automaton states, a deterministic transition function and an initial state. The specification also includes two kinds of effect-related assertions: those that must hold after every transition, and those that must hold after the final transition. Assertions related to program variables (as in Drift) may be specified in the program itself. Whereas assertions related to effects may be specified in the property specification file.

We also implemented two improvements to the dataflow abstract interpretation. First, the Grid-Polyhedron abstract domain [8]—a reduced product of the Polyhedra [6] and the Grid [1] abstract domains—to interpret type refinements of the form of $x \equiv y \mod 2$. Second, we implemented trace partitioning [30] for increased disjunctive precision. Although these benefits are somewhat orthogonal to our contributions, our evaluation (Sec. 8) also experimentally quantifies the disjunctive benefit of trace partitioning in our setting vis-a-vis the benefit of our abstract effect domain. (Note also that these two improvements also benefit the prior Drift tool.)

7.3 Trace Partitioning

The general idea of trace-partitioning for abstract interpretation analysis was first proposed by

Rival and Mauborgne [30]. We motivate trace-partitioning using the example [30] to the right. It is easy to see that the above program does not raise an assertion error as z is either equal to 1 or -1. However, when using convex abstract domains like polyhedra and octagons, z will have an abstract representation that includes the integer 0 because the abstract domain elements of the two branches of the conditional are joined together. Consequently, a static analyzer

```
1 let f x y =
2  let z =
3   if y >= 0 then 1
4   else -1
5  in
6  assert z != 0; x/z
```

```
1 let rec order d c =
                                           1 let rec spend n =
   if d > 0 then
                                               ev (-1);
      if d mod 2 = 0 then ev c
                                               if n \le 0 then 0
        else ev (-c);
                                                 else spend (n - 1)
      order (d - 2) c
                                           6 let main (gas:int) (n:int) =
    else 0
7 let main (dd:int) (cc:int) =
                                               if gas >= n then (ev gas; spend n)
    order dd cc
                                               else 0
                                          Property: \sum_{i}^{N} \leq \text{gas}
Property: Only "c" or "-c" are emitted
                                           1 let rec compute vv bound inc =
1 let rec reent d =
    if d > 0 then
                                               if vv = bound then 0 else
      ev 1; (* Acq *)
                                                 ev vv; compute (inc vv) bound inc
      if nondet() then
                                           4 (* Assume some MAX_INT, MIN_INT *)
        reent (d-1); ev -1 (* Rel *)
                                           5 let min_max v =
5
      else skip
                                               let f = (fun t ->
                                                     if v \ge 0 then t-1 else t+1) in
8 let main d =
                                               if v \ge 0 then compute v (-1 * v) f
    reent d; ev -1 (* Rel *)
                                               else compute v (-1 * v) f
Property: \# \operatorname{Rel} \leq \# \operatorname{Acq}
                                          Property: \forall i > 0. - v < \pi[i] < v
```

Fig. 7. Further examples of our benchmarks. (See the supplement for sources and automata specifications.)

such as ours would raise an undesirable assertion error. To improve the precision in our analysis, we implement a type inference algorithm with trace partitioning.

Informally, for every if-then-else expression, we evaluate the remaining program twice - in the contexts where the condition is true and false. In addition to tracking abstract stacks for increased context-sensitivity, our extended type inference algorithm uses abstract traces to distinguish between the different evaluation paths created by if-then-else expressions leading up to a program node. A combination of abstract stacks and abstract traces enables an even more fine-grained representation of types. This directly alleviates the problem described in the above example. However, naturally, this comes at the cost of processing some nodes of the program multiple times; we evaluate the impact of trace partitioning in the second part of Sec. 8.

7.4 Benchmarks

To our knowledge there are no existing benchmarks for higher-order programs with the general class of SAA properties described, although there are related examples in some fragments of SAA. We thus created the first such suite, assembling benchmarks from the literature, extending them, and creating new ones. We plan to contribute these 21 benchmarks to SV-COMP³. Figure 7 lists some of the benchmarks. These benchmarks test our tool to verify a variety of accumulation automata properties like (clockwise in Fig. 7) tracking disjoint branches of a program, resource analysis, tracking the minimum/maximum of a program variable, and verifying a reentrant lock. Other examples use the accumulator to track properties pertaining to summation, maximum/minimum,

³https://sv-comp.sosy-lab.org/

monotonicity, etc. similar to those found in automata literature [3, 7, 16]. We also include an auction smart contract [36] and adapt some example programs proposed in [27]. These benchmarks involve verification of amortized analysis [11, 12, 14] for a pair of queues, and the verification of liveness and fairness for a non-terminating web-server. Finally, for each benchmark, we created a corresponding *unsafe* variant by tweaking its program or property. The full set of benchmarks are provided in the supplement, and publicly available (*URL for* **ev**DRIFT *omitted for double-blind reviewing*).

8 EVALUATION

All our experiments were conducted on an x86_64 AMD EPYC 7452 32-Core Machine with 125 Gi memory. We used Benchexec⁴ for our experiments to ensure precise measurement of time and memory allocation for each run. In our experiments, we sought to answer two research questions:

- (1) How does **ev**Drift compare with other state-of-the-art automated verification tools for higher-order programs?
- (2) What is the effect of trace-partioning on efficiency and accuracy?

Comparing our approach with other methods. To our knowledge there are no tools that can verify SAA properties of higher-order programs with effects. So to perform some comparison, we combine our translation reduction with tools that can verify assertions of higher-order (effect-free) programs. We chose two somewhat mature such tools: DRIFT (discussed in Sec. 6) and RCAML/PCSAT⁵ (see Secs. 1 and 9 for discussions of other works and tools). RCAML/PCSAT is based on extensions of Constrained Horn Clauses, is part of CoAR⁶, and is built on top of several prior works [17, 20, 32].

RCaml/PCSat lacks support for tuples which appear extensively in our Sec. 6 translation so we also implemented a translation into continuation-passing-style. We also considered Liquid-Haskell [39] which includes an implementation⁷. However, LiquidHaskell is somewhat incomparable because (i) it requires user interaction and our aim is full automation and (ii) the eager-versus-lazy evaluation order difference impacts the language semantics and possible event traces so it is difficult to perform a meaningful comparison. We thus we compared **ev**Drift against Drift (plus the tuple translation) and against RCaml/PCSat (plus the CPS translation).

In our **ev**Drift experiments, we run all our benchmarks using several configurations: various combinations of context sensitivity, trace partitioning, numerical abstract domains, etc. Context sensitivity is either set to "none" (0) or else to a callsite depth of 1. So for example, a configuration with context-sensitivity 1 and trace partitioning enables remembers the last callsite and also the last if-else branch location. For research question #1, we evaluate the end-to-end improvement of all of our work on **ev**Drift over existing tools, so we use Drift (plus the tuple translation) without trace partitioning and **ev**Drift with trace partitioning. Further below in research question #2 we evaluate the degree to which **ev**Drift improves the state of the art due to the use of the abstract effect domain, versus through the use of trace partitioning (as well as the performance overhead of trace partitioning). Regarding abstract domains, we use the loose version of the polyhedra domain [28] for all our benchmarks except for those that involve mod operations where we use the grid-polyhedron domain. For polyhedra, we further consider two different widening configurations: standard widening and widening with thresholds. For widening with thresholds [4], we use a simple heuristic that chooses the conditional expressions in the analyzed programs as well as

⁴https://github.com/sosy-lab/benchexec

⁵We use the RCAML/PCSAT CoAR config, i.e., config/solver/dbg_rcaml_pcsat_tb_ar.json.

⁶https://github.com/hiroshi-unno/coar/

⁷https://ucsd-progsys.github.io/liquidhaskell/

	Drift (via tuple reduction)					RCAML (via cps)				evDi	RIFT
Bench			Mem	Config.					CPU		Config.
1. all-ev-pos	~	2.6	22.3	$\langle tl:0, tp:F, ls \rangle$	M	166.7	1000.0	~	0.2	8.4	$\langle tl:0, tp:F, ls \rangle$
2. auction	M	63.8	1000.0	$\langle tl:0,tp:F,ls\rangle$?	40.1	415.3	~	1.6	15.9	$\langle tl:1, tp:F, ls \rangle$
binomial_heap	**	0.1	10.8	$\langle tl: 1, tp: F, ls \rangle$?	0.0	36.6	~	6.4	40.7	$\langle tl:0,tp:F,ls\rangle$
4. depend	~	0.1	8.6	$\langle tl:1, tp:F, ls \rangle$	M	58.3	1000.0	~	0.0	5.2	$\langle tl:1, tp:T, ls \rangle$
5. disj	?	205.9	199.9	$\langle tl:1, tp:F, ls \rangle$	M	228.2	1000.0	~	9.6	21.3	$\langle tl:0, tp:F, pq \rangle$
6. disj-gte	?	519.2	288.6	$\langle tl:1, tp:F, st \rangle$	M	202.0	1000.0	~	6.4	28.1	$\langle tl:1, tp:F, ls \rangle$
higher-order	~	28.9	34.4	$\langle tl:1, tp:F, ls \rangle$	T	900.3	458.0	~	0.6	12.6	$\langle tl:0, tp:F, ls \rangle$
8. last-ev-even	?	39.8	42.2	$\langle tl:1, tp:F, ls \rangle$?	3.7	100.3	~	9.6	20.4	$\langle tl:1, tp:T, pq \rangle$
lics18-amortized	**	5.6	76.9	$\langle tl: 1, tp: F, ls \rangle$	T	900.3	1000.0	~	41.6	44.6	$\langle tl: 1, tp: F, ls \rangle$
10.lics18-hoshrink	?	164.2	138.6	$\langle tl:1, tp:F, st \rangle$	T	900.3	1000.0	?	0.6	14.3	$\langle tl:0, tp:F, oct \rangle$
11.lics18-web	T	900.3	672.8	$\langle tl:1, tp:F, st \rangle$	M	91.0	1000.0	~	35.5	51.5	$\langle tl:0,tp:F,ls\rangle$
12. market	M	211.0	1000.0	$\langle tl:0,tp:F,ls\rangle$	M	117.3	1000.0	?	37.0	86.4	$\langle tl:0,tp:F,st\rangle$
13. max-min	T	931.0	503.2	$\langle tl:0, tp:F, oct \rangle$	T	900.3	1000.0	~	90.0	80.3	$\langle tl: 1, tp: T, ls \rangle$
14. monotonic	~	16.3	30.6	$\langle tl:1, tp:F, ls \rangle$	M	507.2	1000.0	~	1.1	14.2	$\langle tl:1, tp:F, ls \rangle$
<pre>15. order-irrel</pre>	?	200.6	54.2	$\langle tl:1, tp:F, pq \rangle$?	18.8	144.3	~	6.3	16.9	$\langle tl:1, tp:T, pq \rangle$
<pre>16. overview1</pre>	~	11.5	29.2	$\langle tl:1, tp:F, ls \rangle$	M	396.0	1000.0	~	0.4	13.1	$\langle tl:0,tp:F,ls\rangle$
17. reentr	~	9.6	21.2	$\langle tl:1, tp:F, ls \rangle$	M	94.4	1000.0	~	0.4	11.0	$\langle tl:1, tp:F, ls \rangle$
18. resource-analysis	~	6.8	24.0	$\langle tl:1, tp:F, ls \rangle$	T	900.3	264.5	~	0.4	10.2	$\langle tl:1, tp:F, ls \rangle$
sum-appendix	~	8.2	27.9	$\langle tl:1, tp:F, ls \rangle$?	0.0	36.8	~	0.0	6.1	$\langle tl: 1, tp: T, ls \rangle$
20. sum-of-ev-even	~	13.5	17.6	$\langle tl:0, tp:F, pq \rangle$?	3.6	88.9	~	0.5	10.5	$\langle tl:0, tp:F, pq \rangle$
21. temperature	M	111.3	1000.0	$\langle tl:0,tp:F,st\rangle$	M	324.3	1000.0	~	35.3		$\langle tl:1, tp:F, pg \rangle$
geomean for ✓'s:		6.1				n/a			2.0		. 1 .13,

In addition to the above, we also provide 21 unsafe benchmarks.

evDrift analyzed all of them (using the Config in the last column above) in 273s.

Table 1. Comparison of evDrift against assertion verifiers for effect-free programs: Drift via our tuple reduction and RCaml/PCSat via our cps reduction. For each verifier, we show the result ("✔" for successful verification; "?" for unknown; "T" for timeout - over 900 seconds; "M" for out of memory - over 1000 megabytes), CPU time in seconds, maximum memory used in megabytes and the chosen configuration for Drift and evDrift. evDrift is 30.5× faster than Drift on Drift-verifiable examples, and verified 10 additional benchmarks that Drift could not. RCaml/PCSat either ran out of memory/time, or returned unknown on all benchmarks.

pair-wise inequalities between the variables in scope as pairwise constraints. This heuristic cannot be applied to grid-polyhedron where we only use standard widening. In the discussion below, we report only the result for the configuration that verified the respective benchmark in the least amount of time (as identified in **Config** columns in the tables). For instances where all versions fail to verify a benchmark, we report results for the fastest configuration for brevity. We also include results for other configurations in Apx. D found in the supplement.

Table 1 summarizes the results of our comparison. **ev**Drift significantly outperforms the other two tools in terms of number of benchmarks verified and efficiency. Drift with the tuple reduction was only able to verify 9 of the 21 benchmarks, while **ev**Drift could verify 19. Across all benchmarks that Drift could solve, it had a geomean of 6.1. Across all benchmarks that **ev**Drift could solve, it had a geomean of 2.0. For those benchmarks that *both* Drift and **ev**Drift could verify, **ev**Drift was 30.5× faster. RCaml/PCSat is unable to verify any of our benchmarks, either due to imprecision, timeout, or memory blowup. This is to be expected as the tool is only able to work with a CPS translation of our input which can result in significantly longer programs. Longer programs require significantly more context-sensitivity and the ability to infer complex higher order constraints which lacks in any existing tool. We expect that RCaml/PCSat with support for tuples would be significantly more useful for our use-case compared to the results we show here. For instance, Drift, which is known to have similar performance as RCaml/PCSat [28], does significantly better primarly because it works with smaller programs. However, these are still quite

larger and more complex than regular programs requiring a lot of time for verification and support for non-convex domains. In addition, we also ran **ev**DRIFT on all 21 unsafe variants of the benchmarks. We used the configurations used for their respective safe versions in Table 1. The individual results are omitted for lack of space, but **ev**DRIFT analyzed all unsafe benchmarks in 273 seconds, returning unknown on each of them.

We deduced at least 3 major factors behind evDRIFT's superior performance. (1) evDRIFT evaluates the ev expressions inline which reduces program size significantly. This is leads to the significantly faster runtimes and smaller memory footprint for evDRIFT for all benchmarks. This also reduces a function call and the need to remember another callsite for evDRIFT in some cases like overview1 and sum-appendix where the ev expression might have different arguments at different locations. Moreover, functions' input-output pairs might have non-convex relationships which our abstract domains cannot infer. This is why evDRIFT can verify several benchmarks like disj, lics18-web, higher-order etc., whereas DRIFT cannot. (2) evDRIFT establishes concrete relationships between program variables and accumulator variables leading to increased precision especially in resource-analysis-like benchmarks. (3) evDRIFT's abstract domain adds some inbuilt disjunctivity reasoning that learns different relationships for different final states. This adds efficiency and precision to evDRIFT's analysis as it is able to verify some benchmarks, like disj-gte and disj that have if-then-else statements, without using trace partitioning.

Due to their similarities, **ev**Drift also inherits a few limitations from Drift. **ev**Drift fails to verify lics18-hoshrink that involves non-linear constraints which are not supported by the polyhedra abstract domain. It also fails to verify certain higher order programs like market. **ev**Drift, like Drift, is able to infer rich relationships between input and output types for program variables. However, since accumulator variables are abstracted in a statewise manner, it is much harder to form such relationships for their input and output effects. We believe that this can be improved in the future by more precisely tracking states from input to output effects.

Analyzing the impact of trace-partitioning. Since evDrift uses our abstract effect domain and trace partitioning, a natural question is: which feature provides the more substantial amount of improvement. We now compare evDrift (and 1-context-sensitive Drift with the tuple translation) with and without trace partitioning to answer this question, and to quantify the speed overhead. We summarize the results for these configurations in Table 2. For evDrift, the tool is able to verify two more benchmarks with trace partitioning. Also note that trace partitioning helps Drift verify two additional benchmarks. All these programs have if-then-else clauses that result in disjoint values for subsequent nodes. However, Drift even with trace partitioning still does quite worse than evDrift, as still verifies only 13 out of 21 benchmarks, compared to evDrift's 19 out of 21.

Moreover, for **ev**Drift there are several programs where the running times with trace partitioning are similar to the running times without trace partitioning. This is because these benchmarks do not have nodes that follow an if-then-else clause, and hence there are no instances of multiplicatively analyzed nodes. However, this doesn't happen for Drift due to the nature of the program translation. Overall, trace partitioning slows Drift by 0.7×, and slows **ev**Drift by 0.8×.

9 CONCLUSION

We have introduced the first abstract interpretation for inferring types and effects of higher-order programs. The effect abstract domain disjunctively organizes summaries (abstractions) of partitions of possible event trace prefixes around the concrete automaton states they reach. Our effects

Bench	DRIFT with trace part. Res CPU Mem Config.			evDrift without trace part. Res CPU Mem Config.				evDrift with trace part. Res CPU Mem Config.				
Bellen	ICCS	CIC	WICIII	conng.	Itto	CICI	VICIII	comig.	Ites	CI C	VICIII	comig.
1. all-ev-pos	~	6.9	21.1	$\langle tl:1, tp:T, ls \rangle$	1	0.6	10.3	$\langle tl:1, tp:F, ls \rangle$	1	0.6	10.0	$\langle tl:1, tp:T, ls \rangle$
2. auction	?	180.2	82.6	$\langle tl:1,tp:T,st\rangle$	~	1.6	15.9	$\langle tl:1, tp:F, ls \rangle$	~	1.7	15.8	$\langle tl:1, tp:T, ls \rangle$
binomial_heap	4,4	0.2	10.6	$\langle tl:1,tp:T,pq\rangle$	V	6.6	29.0	$\langle tl:1, tp:F, ls \rangle$	~	6.8	28.4	$\langle tl:1, tp:T, ls \rangle$
4. depend	V	0.1	8.7	$\langle tl:1, tp:T, ls \rangle$	1	0.0	5.5	$\langle tl:1, tp:F, st \rangle$	1	0.0	5.2	$\langle tl:1, tp:T, ls \rangle$
5. disj	T	931.0	220.7	$\langle tl:1, tp:T, st \rangle$	1	16.1	23.8	$\langle tl: 1, tp: F, pq \rangle$	V	22.5	26.9	$\langle tl:1, tp:T, pq \rangle$
6. disj-gte	V	343.7	153.2	$\langle tl:1, tp:T, ls \rangle$	1	6.4	28.1	$\langle tl:1, tp:F, ls \rangle$	1	7.6	26.7	$\langle tl:1, tp:T, ls \rangle$
7. higher-order	1	35.5	35.2	$\langle tl:1, tp:T, ls \rangle$	~	1.1	12.9		1	1.2		$\langle tl:1, tp:T, ls \rangle$
8. last-ev-even	1	341.4	86.5	$\langle tl: 1, tp: T, pq \rangle$?	1.9	15.2	$\langle tl:1, tp:F, ls \rangle$	1	9.6	20.4	$\langle tl:1, tp:T, pq \rangle$
9. lics18-amortized	44	30.9	51.7	$\langle tl:1, tp:T, pq \rangle$	V	41.6	44.6	$\langle tl:1, tp:F, ls \rangle$	1	49.6	45.4	$\langle tl:1, tp:T, ls \rangle$
10.lics18-hoshrink	?	175.4	139.3	$\langle tl:1, tp:T, st \rangle$?	4.0	15.3	$\langle tl:1, tp:F, st \rangle$?	3.4	14.2	$\langle tl:1, tp:T, ls \rangle$
11. lics18-web	T	900.3	944.8	$\langle tl:1, tp:T, ls \rangle$	1	108.4	68.2	$\langle tl:1, tp:F, ls \rangle$	1	111.4	66.1	$\langle tl:1, tp:T, ls \rangle$
12. market	T			$\langle tl:1, tp:T, ls \rangle$		59.6	65.4	$\langle tl:1, tp:F, st \rangle$?	58.4	53.2	$\langle tl:1, tp:T, ls \rangle$
13. max-min	T			$\langle tl:1, tp:T, ls \rangle$?	93.0	37.2	$\langle tl:1, tp:F, pq \rangle$	1	90.0		$\langle tl:1, tp:T, ls \rangle$
14. monotonic	~	21.5	36.1	$\langle tl:1, tp:T, ls \rangle$	V	1.1	14.2	$\langle tl: 1, tp: F, ls \rangle$	1	1.1	13.8	$\langle tl:1, tp:T, ls \rangle$
15. order-irrel	?	465.3		$\langle tl:1, tp:T, pq \rangle$?	1.9		$\langle tl: 1, tp: F, oct \rangle$	V	6.3		$\langle tl:1, tp:T, pq \rangle$
16. overview1	1	12.2		$\langle tl:1, tp:T, ls \rangle$	V	1.0		$\langle tl: 1, tp: F, ls \rangle$	V	1.0		$\langle tl:1, tp:T, ls \rangle$
17. reentr	?	98.7		$\langle tl:1, tp:T, pq \rangle$	1	0.4	11.0		1	0.4		$\langle tl:1, tp:T, ls \rangle$
18. resource-analysis	V	7.6	24.2	$\langle tl:1, tp:T, ls \rangle$	1	0.4	10.2	$\langle tl:1, tp:F, ls \rangle$	1	0.4	9.9	$\langle tl:1, tp:T, ls \rangle$
19. sum-appendix	~	8.3		$\langle tl:1, tp:T, ls \rangle$	1	0.0	6.1	$\langle tl: 1, tp: F, ls \rangle$	1	0.0		$\langle tl:1, tp:T, ls \rangle$
20. sum-of-ev-even	1	37.8		$\langle tl:1,tp:T,pq \rangle$		1.2		$\langle tl:1, tp:F, pq \rangle$	1	1.3		$\langle tl:1, tp:T, pq \rangle$
21. temperature	T	930.9		$\langle tl:1, tp:T, st \rangle$	1	35.3		$\langle tl:1, tp:F, pq \rangle$		46.2		$\langle tl:1, tp:T, pq \rangle$
geomean for √ 's:		24.9		, . 1 , ,		2.7		1 7157		3.3		1 /13/

Table 2. Evaluating the impact of trace partitioning on **ev**Drift's performance. The first set of columns in Tbl. 1 displayed Drift's performance (via the tuple translation) without trace partitioning, which had a geomean of 16.4. In this table, column sets represent (i) Drift with trace partitioning with geomean 24.9, (ii) **ev**Drift without trace partitioning with geomean 2.7, and (iii) **ev**Drift with trace partitioning with geomean 3.3. The colored highlighting shows how, even without trace partitioning, the abstract effect domain of **ev**Drift enables 7 benchmarks to be verified over drift, where as the additional improvement due to trace partitioning is a more modest 3 benchmarks. Additionally, trace partitioning has a slowdown of 0.7 for Drift and a slowdown of 0.8 for **ev**Drift.

are captured in a refinement type-and-effect system and we described how to automate their inference through abstract interpretation. We then showed that our implementation **ev**Drift enables numerous new benchmarks to be verified (or enables faster verification by 30.5× on Drift-verifiable programs), as compared with prior effect-less tools (Drift and RCaml/PCSat) which require translations to encode effects.

Other related work. We discuss some related works in Sec. 1 and as relevant throughout the paper. We now remark in some more detail and mention further related works. The work of Pavlinovic et al. [28] is the most related, but their type system does not include effects or automata, nor do they support any of our new benchmarks. However, we are inspired by their work and build on aspects of their type system, abstract interpretation and implementation. Also related our the type and effect systems of [13, 19, 27]. However, the treatments of effects are not accumulative, which is fundamental to our abstract effect domain. Moreover, those works do not provide an implementation. Hofmann and Chen [13] discuss abstractions of Büchi automata, building their abstractions by using equivalence classes and subsequences of traces to separately summarize the finite and the infinite traces. They then discuss a Büchi type & effect system, but it is not accumulative in nature, nor do they provide an implementation. Murase et al. [26] described a method of verifying temporal properties of higher-order programs through the Vardi [38] reduction to fair termination. We considered using some of their benchmarks⁸, however none were suitable because the overlap

⁸https://www-kb.is.s.u-tokyo.ac.jp/~ryosuke/fair termination/

between their work and ours is limited for two reasons: (i) they focus on verifying infinite execution behaviors while we only verify finite execution properties and (ii) we support expressive SAA properties of finite traces, which they do not support. RCaml is a verifier for OCaml-like programs with refinement types, is based on extensions of Constrained Horn Clauses and is part of CoAR. RCaml was developed as part of several works [17, 20, 32].

We have focused on events/effects that simply emit a value (**ev** *v*) that is unobservable to the program, and merely appears in the resulting event trace. By contrast, numerous recent works are focused on higher-order programming languages with *algebraic effects and their handlers*. Such features allow programmers to define effects in the language, and create exception-like control structures for how to handle the effects. Lago and Ghyselen [22] detail semantics and model checking problems for higher-order programs that have effects such as references, effect handlers, etc. Although this work is quite general, it focuses on semantics and decidability, does not specifically target symbolic accumulator properties, and does not include an implementation. Kawamata et al. [17] discuss a refinement type system for algebraic effects and handlers that supports changes to the so-called "answer type."

Future work. A natural next direction is to automate verification of properties extend beyond safety to liveness specified by, say, Büchi automata or other infinite word automata, perhaps with an accumulator. Such an extension would require infinite trace semantics for the programming language and type & effect system (e.g. [19]), as well as a combination of both least and greatest fixpoint reasoning for abstract interpretations.

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A SOUNDNESS OF ACCUMULATIVE DEPENDENT TYPE AND EFFECT SYSTEM

In this section we prove Theorem 4.1. We start from an instantiation of our type system that satisfies the assumption specified in Section 4. That is, we assume a lattice of base refinement types $\langle \mathcal{B}, \sqsubseteq^b, \perp^b, \sqcap^b, \sqcap^b \rangle$ and a lattice of effects $\langle \Phi, \sqsubseteq^\phi, \sqcup^\phi, \sqcap^\phi, \perp^\phi, \uparrow^\phi \rangle$ with their concretization functions and abstract domain operations.

As outlined in Section 4, we fist establish a connection between abstract typing derivations and derivations in a *concretized* version of the type system.

We obtain this concretized version by instantiating the abstract domain of base refinement types with the powerset lattice $\wp(\mathcal{V} \times Env)$ and the concretization function as identity. We likewise instantiate the abstract domain of dependent effects with the powerset lattice $\wp(\mathcal{V}^* \times Env)$. All abstract domain operations are defined by the most precise operator that satisfies the respective soundness condition. For example, we have for all $\beta \subseteq \mathcal{V} \times Env$ and concrete typing environments Γ :

$$\beta[\Gamma] \stackrel{\text{def}}{=} \beta \cap (\mathcal{V} \times \gamma^{t}(\Gamma))$$
.

To distinguish the operators $\{v=c\}$ for constructing base refinement types from constant values c for the two versions of the type system, we annotate it with their respective domain, writing $\{v=c\}_{\mathcal{B}}$ for the abstract version and $\{v=c\}_{\mathcal{D}(\mathcal{V}\times Env)}$ for the concrete one.

For a type τ in the abstract type system, we define its concretization τ^{γ} recursively as follows:

$$\beta^{\gamma} = \gamma^{b}(\beta)$$

$$(x : (\tau_{1} \& \phi_{1}) \to \tau_{2} \& \phi_{2})^{\gamma} = x : (\tau_{1}^{\gamma} \& \gamma^{\phi}(\phi_{1})) \to \tau_{2}^{\gamma} \& \gamma^{\phi}(\phi_{2})$$

$$(\exists x : \tau_{1}. \tau_{2})^{\gamma} = \exists x : \tau_{1}^{\gamma}. \tau_{2}^{\gamma}.$$

For an abstract typing environment Γ we denote by Γ^{γ} the concrete typing environment obtained from Γ by applying the above concretization pointwise to each binding in Γ . For consistency of notation, we use the short-hand ϕ^{γ} to denote the concrete effect $\gamma^{\phi}(\phi)$ associated with an abstract effect $\phi \in \Phi$.

The following three lemmas establish that (sub)typing derivations in the abstract instantiation of the type system can be replayed in the concrete one.

Lemma A.1. If wf(Γ), then wf(Γ^{γ}).

Proof. Straightforward by induction on the length of Γ and the structure of the types bound in Γ .

LEMMA A.2. If $\Gamma \vdash \tau <: \tau'$, then $\Gamma^{\gamma} \vdash \tau^{\gamma} <: \tau'^{\gamma}$.

PROOF. Straightforward by induction on the derivation of $\Gamma \vdash \tau <: \tau'$ and case analysis on the last rule applied in the derivation. For the base case of rule S-BASE we use the soundness condition on $\beta[\Gamma]$ to establish $\beta^{\gamma}[\Gamma^{\gamma}] \subseteq \gamma^{b}(\beta[\Gamma])$.

LEMMA A.3. If Γ ; $\phi \vdash e : \tau \& \phi'$, then Γ^{γ} ; $\phi^{\gamma} \vdash e : \tau^{\gamma} \& \phi'^{\gamma}$.

PROOF. The proof goes by induction on the derivation of Γ ; $\phi \vdash e : \tau \& \phi'$. We do case analysis on the last typing rule that has been applied in the derivation.

Case T-VAR We have e = x for some x such that $\Gamma(x) = \tau$. We must also have $\phi = \phi'$. From the definition of Γ^{γ} it follows that $\Gamma^{\gamma}(x) = \tau^{\gamma}$ and, hence, Γ^{γ} ; $\phi^{\gamma} \vdash x : \tau^{\gamma} \& \phi^{\gamma}$ using rule T-VAR.

Case T-CONST We have e = c for some c such that $\tau = \{v = c\}_{\mathcal{B}}$. Moreover, we must have $\phi' = \phi$. Using rule T-CONST we infer Γ^{γ} ; $\phi^{\gamma} \vdash x : \{v = x\}_{\varphi(\gamma \vee Env)} \& \phi^{\gamma}$. By assumption on

 $\{v = x\}_{\mathcal{B}}$ we have $\tau^{\gamma} = \gamma^b(\{v = x\}_{\mathcal{B}}) \supseteq \{c\} \times Env = \{v = x\}_{\wp(\mathcal{V} \times Env)}$. It follows that $\{v = x\}_{\wp(\mathcal{V} \times Env)}[\Gamma^{\gamma}] \subseteq \tau^{\gamma}$. As $\phi^{\gamma}[\Gamma] \subseteq \phi^{\gamma}$ holds trivially, we can use rule T-WEAKEN to derive Γ^{γ} ; $\phi^{\gamma} \vdash x : \tau^{\gamma} \& \phi^{\gamma}$.

Case T-EV We have $e = \mathbf{ev} \ e_1$ for some e_1 and $\tau = \{ \nu = \bullet \}_{\mathcal{B}}$. Moreover, there exists ϕ_1 and β_1 such that $\Gamma; \phi \vdash e_1 : \beta_1 \& \phi_1$ and $\phi' = \phi_1 \odot \beta_1$. By induction hypothesis we have $\Gamma^{\gamma}; \phi^{\gamma} \vdash e_1 : \beta_1^{\gamma} \& \phi_1^{\gamma}$. Thus, using rule T-EV we can derive $\Gamma^{\gamma}; \phi^{\gamma} \vdash \mathbf{ev} \ e_1 : \{ \nu = \bullet \}_{\wp(\mathcal{V} \times Env)} \& (\phi^{\gamma} \odot \beta_1^{\gamma})$. We have by assumption that $\tau^{\gamma} = \gamma^b (\{ \nu = \bullet \}_{\mathcal{B}}) \supseteq \{\bullet \} \times Env = \{ \nu = \bullet \}_{\wp(\mathcal{V} \times Env)}$. Moreover, we trivially have $\phi^{\gamma}[\Gamma^{\gamma}] \subseteq \phi^{\gamma}$. Finally, by assumption on \odot we have $\phi'^{\gamma} = \gamma^b (\phi_1 \odot \beta_1) \supseteq \gamma^\phi(\phi_1) \odot \gamma^b(\beta_1) = \phi_1^{\gamma} \odot \beta_1^{\gamma}$. It follows that $(\phi_1^{\gamma} \odot \beta_1^{\gamma})[\Gamma^{\gamma}] \subseteq \phi'^{\gamma}$. Using rule T-WEAKEN we can thus derive $\Gamma^{\gamma}; \phi^{\gamma} \vdash e : \tau^{\gamma} \& \phi'^{\gamma}$.

Case T-APP We have $e = e_1$ e_2 for some e_1 and e_2 . Moreover, there exist ψ , ϕ_1 , and ϕ_2 as well as τ' , τ_1 and τ_2 such that $(\tau \& \phi') = \exists x : \tau_2. (\tau' \& \psi)$, $\Gamma; \phi \vdash e_1 : \tau_1 \& \phi_1$, $\Gamma; \phi_1 \vdash e_2 : \tau_2 \& \phi_2$, and $\tau_1 = x : (\tau_2 \& \phi_2) \to \tau' \& \psi$. By induction hypothesis we have $\Gamma^\gamma; \phi^\gamma \vdash e_1 : \tau_1^\gamma \& \phi_1^\gamma$ and $\Gamma^\gamma; \phi_1^\gamma \vdash e_2 : \tau_2^\gamma \& \phi_2^\gamma$. Using rule T-APP we conclude $\Gamma^\gamma; \phi^\gamma \vdash e : \tau^\gamma \& (\exists x : \tau_2^\gamma . \psi^\gamma)$. We trivially have $\Gamma^\gamma \vdash \tau^\gamma <: \tau^\gamma \text{ and } \phi^\gamma[\Gamma^\gamma] \subseteq \phi^\gamma$. Moreover, by soundness of strengthening we have $(\exists x : \tau_2^\gamma . \psi^\gamma) \subseteq \gamma^\phi(\exists x : \tau_2 . \psi) = \phi'^\gamma$. It follows that $(\exists x : \tau_2^\gamma . \psi^\gamma)[\Gamma^\gamma] \subseteq \phi'^\gamma$. Hence, using rule T-WEAKEN we derive $\Gamma^\gamma; \phi^\gamma \vdash e : \tau^\gamma \& \phi'^\gamma$.

Case T-ABS We have $\phi = \phi'$, $e = (\lambda x. e_1)$ for some x and e_1 , and $\tau = x : (\tau_2 \& \phi_2) \to \tau_1 \& \phi_1$ such that $\Gamma, x : \tau_2; \phi_2 \vdash e_1 : \tau_1 \& \phi_1$. By induction hypothesis, we obtain $\Gamma^{\gamma}, x : \tau_2^{\gamma}; \phi_2^{\gamma} \vdash e_1 : \tau_1^{\gamma} \& \phi_1^{\gamma}$. Using rule T-ABS we can immediately conclude $\Gamma^{\gamma}; \phi^{\gamma} \vdash e : \tau^{\gamma} \& \phi^{\gamma\gamma}$.

Case T-CUT There must exist v, τ', τ'', ψ , and x such that $\Gamma; \phi \vdash v : \tau' \& \phi, x \notin \mathsf{fv}(v), \Gamma, x : \tau'; \phi \vdash e : \tau'' \& \psi, \tau = \exists x : \tau'. \tau'', \text{ and } \phi' = \exists x : \tau'. \psi$. By induction hypothesis, we have $\Gamma^{\gamma}; \phi^{\gamma} \vdash v : \tau'^{\gamma} \& \phi^{\gamma}$ and $\Gamma^{\gamma}, x : \tau'^{\gamma}; \phi^{\gamma} \vdash e : \tau''^{\gamma} \& \psi^{\gamma}$. Using rule T-CUT we can thus derive $\Gamma^{\gamma}; \phi^{\gamma} \vdash e : \exists x : \tau'^{\gamma}. (\tau^{\gamma} \& \psi^{\gamma})$. We trivially have $\Gamma^{\gamma} \vdash \tau^{\gamma} <: \tau^{\gamma} \text{ and } \phi^{\gamma}[\Gamma^{\gamma}] \subseteq \phi^{\gamma}$. Moreover, by soundness of strengthening we have $(\exists x : \tau'^{\gamma}. \psi^{\gamma}) \subseteq \gamma^{\phi}(\exists x : \tau'. \psi) = \phi'^{\gamma}$. It follows that $(\exists x : \tau'^{\gamma}. \psi^{\gamma})[\Gamma^{\gamma}] \subseteq \phi'^{\gamma}$. Hence, using rule T-WEAKEN we derive $\Gamma^{\gamma}; \phi^{\gamma} \vdash e : \tau^{\gamma} \& \phi'^{\gamma}$.

Case T-WEAKEN There must exist ψ , ψ' , and τ' such that $\phi[\Gamma] \sqsubseteq^{\phi} \psi$, $\Gamma; \psi \vdash e : \tau' \& \psi'$, $\Gamma \vdash \tau' <: \tau$, and $\psi'[\Gamma] \sqsubseteq^{\phi} \phi'$. By induction hypothesis, we have $\Gamma^{\gamma}; \psi^{\gamma} \vdash e : \tau'^{\gamma} \& \psi'^{\gamma}$. Because of monotonicity of γ^{ϕ} , we have $\gamma^{\phi}(\phi[\Gamma]) \subseteq \gamma^{\phi}(\psi) = \psi^{\gamma}$. Because of the soundness assumption on effect strengthening, we also have $\phi^{\gamma}[\Gamma^{\gamma}] = \gamma^{\phi}(\psi) \cap \gamma^{t}(\Gamma) \subseteq \gamma^{\phi}(\phi[\Gamma])$. Thus, we obtain $\phi^{\gamma}[\Gamma^{\gamma}] \subseteq \psi^{\gamma}$. Using similar reasoning, we infer $\psi'^{\gamma}[\Gamma^{\gamma}] \subseteq \phi'^{\gamma}$. Finally, we apply Lemma A.2 to obtain $\Gamma^{\gamma} \vdash \tau'^{\gamma} <: \tau^{\gamma}$. Then we can use rule T-WEAKEN to derive $\Gamma^{\gamma}; \phi^{\gamma} \vdash e : \tau^{\gamma} \& \phi^{\gamma}$.

We next show that the concrete instantiation of the type system satisfies progress and preservation. To ease notation, from here on meta variables like τ , ϕ , and Γ refer to types and effects of the concrete instantiation of the type system (unless specified otherwise).

We start with two technical lemmas that are needed to prove progress.

Lemma A.4 (Subtyping monotone). If $\Gamma \vdash \tau <: \tau', \langle v, \rho \rangle \in \tau$, and $\rho \in \gamma^{t}(\Gamma)$, then $\langle v, \rho \rangle \in \tau'$.

Lemma A.5 (Value typing). If Γ ; $\phi \vdash v : \tau \& \phi'$, then for all ϕ'' with $dom(\phi'') \subseteq dom(\Gamma)$, we have ϕ'' , Γ ; $\phi'' \vdash v : \tau \& \phi''$. Moreover, for all $\rho \in \gamma^{t}(\Gamma)$, $\langle v, \rho \rangle \in \gamma^{t}(\tau)$.

PROOF. The proof goes by induction on the derivation of Γ ; $\phi \vdash v : \tau \& \phi'$. We do case analysis on the last typing rule that has been applied in the derivation.

Case T-VAR, T-APP, **and** T-EV These rules cannot be the last rules that have been applied in the derivation since they do not apply to values.

Case T-CONST We must have $\tau = \{v = v\} \in \mathcal{B}$ and $\phi' = \phi$. Let ϕ'' be such that $dom(\phi'') \subseteq dom(\Gamma)$. Using rule T-CONST we can immediately derive $\Gamma; \phi'' \vdash v : \tau \& \phi''$. Moreover, let

 $\rho \in \gamma^{t}(\Gamma)$. By assumption on the operator $\{v = v\}$ we have $\{v = v\} \supseteq \{v\} \times Env$. It follows that we have $\langle v, \rho \rangle \in \{v = v\} = \tau = \gamma^{t}(\tau)$.

Case T-ABS We must have $v = \lambda x$. e for some x and e. Moreover, there must be τ_1 and τ_2 , ϕ_1 and ϕ_2 such that $\Gamma, x : \tau_2; \phi_2 \vdash e : \tau_1 \& \phi_1$ and $\tau = (x : (\tau_2 \& \phi_2) \to \tau_1 \& \phi_1)$. Let ϕ'' be such that $\text{dom}(\phi'') \subseteq \text{dom}(\Gamma)$. Using rule T-ABS we can immediately derive $\Gamma; \phi'' \vdash v : \tau \& \phi''$. Moreover, let $\rho \in \gamma^t(\Gamma)$. We have $\langle v, \rho \rangle \in \mathcal{V} \times Env = \gamma^t(\tau)$.

Case T-WEAKEN There must exist ψ , ψ' , and τ' such that $\phi[\Gamma] \sqsubseteq^{\phi} \psi$, $\Gamma; \psi \vdash v : \tau' \& \psi'$, $\Gamma \vdash \tau' <: \tau$, and $\psi'[\Gamma] \sqsubseteq^{\phi} \phi'$. Let ϕ'' be such that $dom(\phi'') \subseteq dom(\Gamma)$. By induction hypothesis, we conclude $\Gamma; \phi'' \vdash v : \tau' \& \phi''$. By monotonicity of strengthening, we have $\phi''[\Gamma] \sqsubseteq^{\phi} \phi''$. Using rule T-WEAKEN we can thus conclude $\Gamma; \phi'' \vdash v : \tau \& \phi''$. Moreover, let $\rho \in \gamma^{t}(\Gamma)$. By induction hypothesis, we have $\langle v, \rho \rangle \in \gamma^{t}(\tau')$. Then by Lemma A.4 we have $\langle v, \rho \rangle \in \gamma^{t}(\tau)$.

Case T-CUT There must exist v', τ' , τ'' , ψ , and x such that $\Gamma; \phi \vdash v' : \tau' \& \phi, x \notin \mathsf{fv}(v), \Gamma, x : \tau'; \phi \vdash v : \tau'' \& \psi, \tau = \exists x : \tau' \cdot \tau'', \text{ and } \phi' = \exists x : \tau' \cdot \psi.$ Let ϕ'' be such that $\mathsf{dom}(\phi'') \subseteq \mathsf{dom}(\Gamma)$. Then also $\mathsf{dom}(\phi'') \subseteq \mathsf{dom}(\Gamma, x : \tau')$. It follows by induction hypothesis that $\Gamma, x : \tau'; \phi'' \vdash v : \tau'' \& \phi''$. Using rule T-CUT we can thus derive $\Gamma; \phi'' \vdash v : \tau \& \phi''$. Moreover, let $\rho \in \gamma^{\mathsf{t}}(\Gamma)$. By induction hypothesis, we have $\langle v', \rho \rangle \in \gamma^{\mathsf{t}}(\tau')$. Since $\notin \mathsf{dom}(\Gamma)$, it follows that $\rho[x \mapsto v'] \in \gamma^{\mathsf{t}}(\Gamma, x : \tau')$. Then again by induction hypothesis, $\langle v, \rho[x \mapsto v'] \rangle \in \gamma^{\mathsf{t}}(\tau'')$. From the definition of γ^{t} , we conclude $\langle v, \rho \rangle \in \gamma^{\mathsf{t}}(\exists x : \tau', \tau'') = \gamma^{\mathsf{t}}(\tau)$.

We are now ready to show that the concrete instantiation of the type system satisfies progress.

THEOREM A.6 (PROGRESS). Let e be a closed term. If Γ ; $\phi \vdash e : \tau \& \phi'$, then for all $\langle \pi, \rho \rangle \in \phi[\Gamma]$, e is a value and $\langle \pi, \rho \rangle \in \phi'$ or there exist π' and e' such that $\langle e, \pi \rangle \to \langle e', \pi' \rangle$.

PROOF. The proof goes by induction on the derivation of Γ ; $\phi \vdash e : \tau \& \phi'$. We do case analysis on the last typing rule that has been applied in the derivation.

Case T-WEAKEN We have $\Gamma; \psi \vdash e : \tau' \& \psi'$ for some ψ, τ' , and ψ' such that $\phi[\Gamma] \subseteq \psi, \psi'[\Gamma] \subseteq \phi'$, and $\Gamma \vdash \tau' <: \tau$. Let $\langle \pi, \rho \rangle \in \phi[\Gamma]$. Then also $\rho \in \gamma^t(\Gamma)$. From $\phi[\Gamma] \subseteq \psi$ we then conclude $\langle \pi, \rho \rangle \in \psi[\Gamma]$. It follows from the induction hypothesis that e is a value and $\langle \pi, \rho \rangle \in \psi'$ or there exist π' and e' such that $\langle e, \pi \rangle \to \langle e', \pi' \rangle$. In the second case we are done. In the first case, we use $\psi'[\Gamma] \subseteq \phi'$ and $\rho \in \gamma^t(\Gamma)$ to conclude that $\langle \pi, \rho \rangle \in \phi'$.

Case T-CUT We have $\tau = \exists x : \tau'.\tau''$ and $\phi = \exists x : \tau'.\phi''$ such that $\Gamma; \phi \vdash v : \tau'\&\phi$, and $\Gamma, x : \tau'; \phi \vdash e : \tau''\&\phi''$. Therefore, we must also have $\operatorname{wf}(\Gamma, x : \tau')$. Let $\langle \pi, \rho \rangle \in \phi[\Gamma]$. Then also $\rho \in \gamma^{\operatorname{t}}(\Gamma)$. By Lemma A.5, we have $\langle v, \rho \rangle \in \gamma^{\operatorname{t}}(\tau')$. It follows from the definition of $\gamma^{\operatorname{t}}$ and $\operatorname{wf}(\Gamma, x : \tau')$ that $\rho[x \mapsto v] \in \gamma^{\operatorname{t}}(\Gamma, x : \tau')$. From the monotonicity of strengthening, it follows that $\langle v, \rho \rangle \in \phi[\emptyset] = \phi$. Moreover, $\operatorname{dom}(\phi) \subseteq \operatorname{dom}(\Gamma)$ and $x \notin \operatorname{dom}(\Gamma)$ implies $x \notin \operatorname{dom}(\phi)$. Therefore, $\langle \pi, \rho[x \mapsto v] \rangle \in \phi$. By the definition of strengthening we now conclude $\langle \pi, \rho[x \mapsto v] \rangle \in \phi[\Gamma, x : \tau']$. From the induction hypothesis, it then follows that either e is a value and $\langle \pi, \rho[x \mapsto v] \rangle \in \phi''$ or there exists e' and π' , such that $\langle e, \pi \rangle \to \langle e', \pi' \rangle$. In the second case we are done. In the first case, we note that $\langle \pi, \rho[x \mapsto v] \rangle \in \phi''$ and $\langle v, \rho \rangle \in \gamma^{\operatorname{t}}(\tau')$ implies $\langle \pi, \rho \rangle \in (\exists x : \tau', \phi'') = \phi'$.

Case T-CONST **and** T-ABS In both cases e is a value and $\phi = \phi'$. So the claim follows immediately.

Case T-VAR By assumption, *e* is closed. So this rule cannot be the last rule used in the typing derivation.

Case T-EV We have $e = \mathbf{ev} \ e_1$ for some e_1 . Moreover, there exists ϕ_1 and β_1 such that $\Gamma; \phi \vdash e_1 : \beta_1 \& \phi_1$ and $\phi' = \phi_1 \odot \beta_1$.

Suppose e_1 is not a value. Let $\langle \pi, \rho \rangle \in \phi[\Gamma]$ and $\rho \in \gamma^t(\Gamma)$. By induction hypothesis, there must exist π' and e_1' such that $\langle e_1, \pi \rangle \to \langle e_1', \pi' \rangle$. Thus, we also have $\langle e, \pi \rangle \to \langle e', \pi' \rangle$ for $e' = \mathbf{ev} \ e_1'$ by rule E-CONTEXT.

Suppose on the other hand that e_1 is a value. Let $\langle \pi, \rho \rangle \in \phi[\Gamma]$. We have $\langle e, \pi \rangle \to \langle e', \pi' \rangle$ for $e' = \bullet$ and $\pi' = \pi \cdot e_1$ by rule E-EV.

Case T-APP We have $e = e_1$ e_2 for some e_1 and e_2 . Moreover, there exist ψ , ϕ_1 and ϕ_2 as well as τ' , τ_1 and τ_2 such that Γ ; $\phi \vdash e_1 : \tau_1 \& \phi_1$, Γ ; $\phi_1 \vdash e_2 : \tau_2 \& \phi_2$, and $\tau_1 = x : (\tau_2 \& \phi_2) \to \tau' \& \psi$. If e_1 is not a value, then by induction hypothesis, for all $\langle \pi, \rho \rangle \in \phi[\Gamma]$ there exist π' and e_1' such that $\langle e_1, \pi \rangle \to \langle e_1', \pi' \rangle$. It follows that $\langle e, \pi \rangle \to \langle e_1', \pi' \rangle$ for $e' = e_1'$ e_2 by rule E-CONTEXT.

The case where e_1 is a value but e_2 is not is similar to the previous case.

Thus, let us assume that both e_1 and e_2 are values. Since $\tau_1 = x : (\tau_2 \& \phi_2) \to \tau' \& \psi$ and e_1 is a value, we must have $e_1 = \lambda x$. e for some x and e. It follows for all $\langle \pi, \rho \rangle \in \phi[\Gamma]$ that $\langle e, \pi \rangle \to \langle e', \pi' \rangle$ for $e' = e[e_2/x]$ and $\pi' = \pi$ by rule E-APP.

We next turn to proving preservation. Again, we start with some technical lemmas.

LEMMA A.7. If $\Gamma, x : \tau_x, y : \tau_u; \phi \vdash e : \tau \& \phi'$ and $\mathsf{wf}(\Gamma, y : \tau_u)$, then $\Gamma, y : \tau_u, x : \tau_x; \phi \vdash e : \tau \& \phi'$.

PROOF. The proof goes by induction on the derivation of $\Gamma, x : \tau_x, y : \tau_y; \phi \vdash e : \tau \& \phi'$ using the fact that $\operatorname{wf}(\Gamma, x : \tau_x, y : \tau_y)$ and $\operatorname{wf}(\Gamma, y : \tau_y)$ implies (1) $\operatorname{wf}(\Gamma, y : \tau_y, x : \tau_x)$, (2) $\gamma^{\operatorname{t}}(\Gamma, x : \tau_x, y : \tau_y) = \gamma^{\operatorname{t}}(\Gamma, y : \tau_y, x : \tau_x)$, and (3) for all $z \in \operatorname{dom}(\Gamma, x : \tau_x, y : \tau_y) = \operatorname{dom}(\Gamma, y : \tau_y, x : \tau_x)$, $(\Gamma, y : \tau_y, x : \tau_x)(z) = (\Gamma, x : \tau_x, y : \tau_y)(z)$.

LEMMA A.8. If $\Gamma \vdash \tau <: \tau'$ and $wf(\Gamma, x : \tau_x)$, then $\Gamma, x : \tau_x \vdash \tau <: \tau'$.

PROOF. The proof goes by induction on the derivation of $\Gamma \vdash \tau <: \tau'$, using the fact that for all $\beta \subseteq \mathcal{V} \times \mathit{Env}$, we have

$$\beta[\Gamma, x : \tau_x]$$

$$= \beta \cap \gamma^{t}(\Gamma, x : \tau_x)$$

$$= \beta \cap \gamma^{t}(\Gamma) \cap \{ \rho \mid \exists v. \langle v, \rho \rangle \in \gamma^{t}(\tau_x) \}$$

$$\subseteq \beta \cap \gamma^{t}(\Gamma)$$

$$= \beta[\Gamma]$$

and, similarly, that for all $\phi \subseteq \mathcal{V}^* \times Env$, we have $\phi[\Gamma, x : \tau_x] \subseteq \phi[\Gamma]$.

LEMMA A.9. If Γ ; $\phi \vdash e : \tau \& \phi'$ and $wf(\Gamma, x : \tau_x)$, then $\Gamma, x : \tau_x$; $\phi \vdash e : \tau \& \phi'$.

PROOF. We prove the claim by induction on the derivation of Γ ; $\phi \vdash e : \tau \& \phi'$. We proceed by case analysis on the last rule that is applied in the derivation. We only show some of the more interesting cases.

Case T-VAR We have $\phi = \phi'$ and e = y for some $y \in Var$ such that $\Gamma(y) = \tau$. Since wf $(\Gamma, x : \tau_x)$, we must have $x \neq y$. Hence, $(\Gamma, x : \tau_x)(y) = \tau$. Using rule T-VAR, we then derive $\Gamma, x : \tau_x; \phi \vdash e : \tau \& \phi'$.

Case T-ABS We have $\phi = \phi'$, $e = (\lambda y. e_1)$ for some y and e_1 , and $\tau = y: (\tau_2 \& \phi_2) \to \tau_1 \& \phi_1$ such that $\Gamma, y: \tau_2; \phi_2 \vdash e_1: \tau_1 \& \phi_1$. Without loss of generality we have $x \neq y$. Since wf $(\Gamma, x: \tau_x)$ and wf $(\Gamma, y: \tau_2)$, we also have wf $(\Gamma, y: \tau_2, x: \tau_x)$. By induction hypothesis, we obtain $\Gamma, y: \tau_2, x: \tau_x; \phi_2 \vdash e_1: \tau_1 \& \phi_1$. Using Lemma A.7 we infer $\Gamma, x: \tau_x y: \tau_2; \phi_2 \vdash e_1: \tau_1 \& \phi_1$. Thus, we derive $\Gamma, x: \tau_x; \phi \vdash e: \tau \& \phi'$ using rule T-ABS.

Case T-WEAKEN We have $\Gamma; \psi \vdash e : \tau' \& \psi'$ for some ψ, τ' , and ψ' such that $\phi[\Gamma] \subseteq \psi, \psi'[\Gamma] \subseteq \phi'$, and $\Gamma \vdash \tau' <: \tau$. By induction hypothesis, we have $\Gamma, x : \tau_x; \psi \vdash e : \tau' \& \psi'$. Moreover, using Lemma A.8, we infer $\Gamma, x : \tau_x \vdash \tau' <: \tau$. Next, we use $\phi[\Gamma] \subseteq \psi$ and $\phi[\Gamma, x : \tau_x] \subseteq \phi[\Gamma]$ to infer $\phi[\Gamma, x : \tau_x] \subseteq \psi$. Using similar reasoning, we infer $\psi'[\Gamma, x : \tau_x] \subseteq \phi'$. Thus, we can apply rule T-WEAKEN to derive the desired $\Gamma, x : \tau_x; \phi \vdash e : \tau \& \phi'$.

Lemma A.10 (Substitution). If Γ ; $\phi_v \vdash v : \tau_v \& \phi'_v$ and $\Gamma, x : \tau_v, \Gamma'; \phi \vdash e : \tau \& \phi'$, then $\Gamma, x : \tau_v, \Gamma'; \phi \vdash e[v/x] : \tau \& \phi'$.

PROOF. We prove the claim by induction on the derivation of $\Gamma, x : \tau_v, \Gamma'; \phi \vdash e : \tau \& \phi'$. We proceed by case analysis on the last rule that is applied in the derivation. We only show some of the cases. The omitted cases are similar to the case for T-ABS but follow simpler reasoning.

Case T-CONST We have $\phi = \phi'$ and e = c for some constant value c. It follows e[v/x] = c. Hence, $\Gamma, x : \tau_v, \Gamma'; \phi \vdash e[v/x] : \tau \& \phi'$.

Case T-VAR We have $\phi = \phi'$ and e = y for some $y \in Var$ such that $(\Gamma, x \mapsto \tau_v, \Gamma')(y) = \tau$. If $x \neq y$, then e[v/x] = y. Hence, we immediately obtain $\Gamma, x : \tau_v, \Gamma'; \phi \vdash e[v/x] : \tau \& \phi'$.

On the other hand, if x = y, then $\tau = \tau_v$ and e[v/x] = v. Using Γ ; $\phi_v \vdash v : \tau_v \& \phi_v'$ and Lemma A.5, we first infer Γ ; $\phi \vdash v : \tau_v \& \phi$. By repeatedly applying Lemma A.9, we can then derive the desired Γ , $x : \tau_v$, Γ' ; $\phi \vdash v : \tau_v \& \phi$.

Case T-ABS We have $\phi = \phi'$, $e = (\lambda y. e_1)$ for some y and e_1 , and $\tau = y : (\tau_2 \& \phi_2) \to \tau_1 \& \phi_1$ such that $\Gamma, x : \tau_v, \Gamma', y : \tau_2; \phi_2 \vdash e_1 : \tau_1 \& \phi_1$. By induction hypothesis, we obtain $\Gamma, x : \tau_v, \Gamma', y : \tau_2; \phi_2 \vdash e_1[v/x] : \tau_1 \& \phi_1$. Thus, using rule T-ABS and $x \neq y$, we derive $\Gamma, x : \tau_v, \Gamma'; \phi_2 \vdash (\lambda y. e_1)[v/x] : \tau \& \phi$.

We now prove that the concrete instantiation of the type system satisfies progress.

THEOREM A.11 (PRESERVATION). If $\langle e, \pi \rangle \to \langle e', \pi' \rangle$ and $\phi \vdash e : \tau \& \phi'$ where $\langle \pi, \rho \rangle \in \phi$ for some ρ . Then there exists ϕ'' such that $\phi'' \vdash e' : \tau \& \phi'$ and $\langle \pi', \rho \rangle \in \phi''$.

PROOF. We prove the claim by induction on the derivation of $\phi \vdash e : \tau \& \phi'$. We only discuss the cases for rules T-EV and T-APP as they are the most involved.

Case T-EV We have $e = \mathbf{ev} \ e_1$ for some e_1 and $\tau = \{ \nu = \bullet \}$. Moreover, there exists β and ϕ_1 such that $\phi \vdash e_1 : \beta \& \phi_1$ and $\phi' = \phi_1 \odot \beta_1$.

The case where e_1 is not a value follows from the induction hypothesis.

If e_1 is a value, then $e' = \bullet$ and $\pi' = \pi \cdot e_1$. Moreover, by Lemma A.5 we can assume that $\phi_1 = \phi$ and $\langle e_1, \rho \rangle \in \beta$. From $\langle e_1, \rho \rangle \in \gamma^{\mathsf{t}}(\tau_1)$, $\langle \pi, \rho \rangle \in \phi_1$, and the requirement on \odot , we conclude that $\langle \pi', \rho \rangle \in \phi'$. The claim then follows for $\phi'' = \phi'$.

Case T-APP. We have $e = e_1$ e_2 for some e_1 and e_2 . Moreover, there exist ϕ_1 , ϕ_2 , and ψ as well as τ_1 , τ_2 , and τ' such that $\phi \vdash e_1 : \tau_1 \& \phi_1$, $\phi_1 \vdash e_2 : \tau_2 \& \phi_2$, $\tau_1 = x : (\tau_2 \& \phi_2) \to \tau' \& \psi$, and $\tau \& \phi' = \exists x : \tau_2 . (\tau' \& \psi)$.

If e_1 is not a value, then we must have $e'=e'_1$ e_2 for some e'_1 such that $\langle e_1,\pi_1\rangle \to \langle e'_1,\pi'_1\rangle$ for some π'_1 . It follows by the induction hypothesis that there exists ϕ'' such that $\phi'' \vdash e'_1 : \tau_1 \& \phi_1$ and $\langle \pi'_1,\rho\rangle \in \phi''$. Thus, using rule T-APP we conclude $\phi'' \vdash e' : \tau \& \phi'$.

The case where e_1 is a value but e_2 is not is similar to the previous case.

Thus, let us assume that both e_1 and e_2 are values. Since $\tau_1 = x : (\tau_2 \& \phi_2) \to \tau' \& \psi$ and e_1 is a value, we must have $e_1 = \lambda x.$ e for some x and e. It follows that $e' = e[e_2/x]$ and $\pi' = \pi$. Moreover, from Lemma A.5 it follows that we may assume $\phi = \phi_1 = \phi_2$. By rule T-ABS, we must have $x : \tau_2; \phi_2 \vdash e : \tau' \& \psi$. By Lemma A.10 we have $x : \tau_2; \phi_2 \vdash e[e_2/x] : \tau' \& \psi$. Thus, using rule T-CUT, we infer $\phi_2 \vdash e' : \tau \& \phi'$. Since $\pi' = \pi$, $\langle \pi, \rho \rangle \in \phi$ and $\phi = \phi_1 = \phi_2$, the claim then follows by choosing $\phi'' = \phi$.

Finally, we are ready to prove Theorem 4.1.

PROOF OF THEOREM 4.1. Assume that $\phi \vdash e : \tau \& \phi'$ holds in the abstract type system and let $\langle \pi, \rho \rangle \in \gamma^b(\phi)$ and $\langle e', \pi' \rangle$ such that $\langle e, \pi \rangle \leadsto \langle e', \pi' \rangle$.

Let $\langle e, \pi \rangle = \langle e_0, \pi_0 \rangle \to \langle e_1, \pi_1 \rangle \to \cdots \to \langle e_n, \pi_n \rangle = \langle e', \pi' \rangle$ be a sequence of reduction steps used to obtain $\langle e', \pi' \rangle$ from $\langle e, \pi \rangle$ for $n \geq 0$.

We show by induction on $i, 0 \le i \le n$ that there exist ϕ_i such that $\phi_i \vdash e : \tau^{\gamma} \& \phi'^{\gamma}$ and $\langle \pi_i, \rho \rangle \in \phi_i$. If i = 0, we can use Lemma A.3 to conclude that $\phi^{\gamma} \vdash e_0 : \tau^{\gamma} \& \phi'^{\gamma}$. The claim then follows for $\phi_0 = \phi^{\gamma}$.

If $0 < i \le n$, then by induction hypothesis we have $\phi_{i-1} \vdash e_{i-1} : \tau^{\gamma} \& \phi'^{\gamma}$ for some ϕ_{i-1} such that $\langle \pi_{i-1}, \rho \rangle \in \phi_{i-1}$. Using Theorem A.11, we conclude that there exists ϕ_i such that $\phi_i \vdash e_i : \tau^{\gamma} \& \phi'^{\gamma}$ and $\langle \pi_i, \rho \rangle \in \phi_i$.

We thus have $\phi_n \vdash e' : \tau^{\gamma} \& \phi'^{\gamma}$ and $\langle \pi', \rho \rangle \in \phi_n$. By assumption there is no $\langle e'', \rho'' \rangle$ such that $\langle e', \pi' \rangle \rightarrow \langle e'', \pi'' \rangle$. Using Theorem A.6 we thus conclude that e' must be a value and $\langle \pi', \rho \rangle \in \phi'^{\gamma}$.

B SOUNDNESS OF TYPE AND EFFECT INFERENCE VIA PROGRAM TRANSLATION

We assume that strengthening operator is extended with the following clauses:

$$t[x \leftarrow \phi]^d = t \qquad t[x \leftarrow (t_1 \times t_2)]^d = t \qquad (t_1 \times t_2)[x \leftarrow t']^d = (t_1[x \leftarrow t']^d \times t_2[x \leftarrow t']^d)$$

Proposition B.1. If $\beta^d \in \mathcal{R}_X^t$ with scope X, $\beta \in \mathcal{B}$ and $X = dom(\beta)$ then $\beta^d = \beta$ iff $\gamma^d(\beta^d) \cup (\mathcal{V} \times Env) = \gamma(\beta)$

PROOF. o The proof is immediate from the definition of types.

A similar result can be shown for base types ϕ^d representing event sequences. Hereafter, β (and ϕ) denotes base type (and effect) both in the effect-free language and in our language that agrees on the scope and represent the same values (event sequences).

Recall the two simultaneously inductive backwards translation functions that embed types in the translated program back to types and type and effects respectively.

$$\begin{split} \ddot{\mathcal{T}}^t(\bot^d) &\stackrel{\text{def}}{=} \bot^b \qquad \ddot{\mathcal{T}}^t(\top^d) \stackrel{\text{def}}{=} \top^b \qquad \ddot{\mathcal{T}}^t(\beta) \stackrel{\text{def}}{=} \beta \\ \ddot{\mathcal{T}}^t((x:t_x) &\to (\varpi_x:\phi_x) \to t)) \stackrel{\text{def}}{=} x: \ddot{\mathcal{T}}^t(t_x) \& \phi_x \to \ddot{\mathcal{T}}^{te}(t) \\ \ddot{\mathcal{T}}^{te}(\langle t, \phi \rangle) \stackrel{\text{def}}{=} \ddot{\mathcal{T}}^t(\tau) \& \phi \end{split}$$

For all the other cases both $\ddot{\mathcal{T}}^t$ and $\ddot{\mathcal{T}}^{te}$ are undefined. We lift this backwards type translation function to typing environments

$$\dot{\tilde{\mathcal{T}}}^t(\emptyset) = \emptyset \qquad \dot{\tilde{\mathcal{T}}}^t(\Gamma^d, x:t) = \dot{\tilde{\mathcal{T}}}^t(\Gamma^d), x:\dot{\tilde{\mathcal{T}}}^t(t)$$

Note that even the backward translation functions are partially defined, they are sufficient to state the following lemmas and theorem that must hold only for the typing derivations of translated programs. It's immediate to see that, given a closed program, the typing judgments of the corresponding translated terms relate typing contexts on which the backward translation is defined. That does not impose a restriction on the typing derivation of the subexpressions of the translated terms. In the remaining part of this section, when referring to a typing judgment or subtyping relation, we consider only typing environments that are in the domain of $\tilde{\mathcal{T}}^t$. Henceforth, we refer to them as backward translatable type or typing environment.

The following lemma states that strengthening a base type with respect to a backward translatable typing environment is the same as strengthening it with the translated typing environment in the type and effect system

Lemma B.2. For a basic refinement type β , Γ^d on $\beta[\Gamma^d]^d = \beta[\tilde{\mathcal{T}}^t(\Gamma^d)]$

PROOF. The proof goes by induction on the length of the environment Γ^d .

Case Base We have $\Gamma^d = \emptyset$. The proof is immediate from the base definition of \mathcal{T}^t function on the empty typing environment.

Case Induction We assume the induction hypothesis $\beta[\Gamma^d]^d = \beta[\tilde{\mathcal{T}}^t(\Gamma^d)]$ and we set to prove that $\beta[\Gamma^d, x:t]^d = \beta[\tilde{\mathcal{T}}^t(\Gamma^d, x:t)]$. We proceed by case analysis on the structure of a backwards translatable type t.

Case $t = \bot^d$. By the definition we know that $\beta[\Gamma^d, x : \bot^d]^d = \beta[\Gamma^d]^d \sqcap^b \beta[x \leftarrow \bot^d]$. From the definition of type strengthening operator on types, and the definition of meet we get $\beta[\Gamma^d, x : \bot^d]^d = \bot^b$. Consider now the right side of the equation that after expanding the backwards type translation on typing environment is $\beta[\tilde{\mathcal{T}}^t(\Gamma^d), x : \tilde{\mathcal{T}}^t(\bot^d)]$. Using the translation definition for type \bot^d , and then using the definition of the base type strengthening with an environment we get $\beta[\tilde{\mathcal{T}}^t(\Gamma^d), x : \bot^b] = \bot^b$, thus concluding the proof of this case.

Case $t= \top^d$. Following a similar approach, we expand the strengthening operator on the left side and get $\beta[\Gamma^d, x: \top^d]^d = \beta[\Gamma^d]^d$. By the definitions of the strengthening operator and the backwards translation of type \top^d , and by the fact that the concretization function is top-strict we obtain that $\beta[\tilde{\mathcal{T}}^t(\Gamma^d), x: \top^b] = \beta[\tilde{\mathcal{T}}^t(\Gamma^d)]$. We finalize the proof of this case by applying the induction hypothesis.

Case $t = \beta'$. Expanding both sides of the equations and then applying the respective definitions we get the following proof obligation: $\beta[\Gamma^d]^d \cap^b \beta[x \leftarrow \beta'] = \beta[\tilde{\mathcal{T}}^t(\Gamma^d), x : \beta']$. Using the definitions and the induction hypothesis it's easy to see that they agree in terms of their semantics given by their respective concretization functions because both types represent the most precise abstraction of the same set of concrete values and the infimum is unique. We use proposition B.1 we conclude the proof

Case $t = (x : t_x) \to (\varpi : \phi) \to t$. The proof is immediate because the strengthening of a base type with a dependency variable bound to a function is similar to an identity operation. The argument for this case is the same as Case T-Top.

A similar result can be proved for strengthening a base type ϕ representing effect sequences.

Lemma B.3. For an effect
$$\phi$$
, $\phi[\Gamma^d]^d = \phi[\tilde{\mathcal{T}}^t(\Gamma^d)]$

PROOF. Because ϕ are base refinement types drawn from the domain Φ , the proof is similar to the proof for lemma B.2.

We ease the notation by dropping the superscript for the strengthening operator when it is clear from the context in which type system it is applied.

In the next lemma we show how that if we have a subtyping derivations in the target type system for backward translatable types and typing environments then we can obtain a derivation for subtyping in the type and effect system. As expected, the same result holds for effects with respect to their order relation.

Lemma B.4. For all backward translatable $\Gamma^d, t, t', if t[\Gamma^d] <: ^d t'[\Gamma^d]$ then $\tilde{\mathcal{T}}^t(\Gamma^d) \vdash \tilde{\mathcal{T}}^t(t) <: \tilde{\mathcal{T}}^t(t')$

PROOF. The proof is by simultaneous induction over the depth of t and t'. We case split on subtyping rules that apply to backward translatable types.

Case S-BOT[D] We have $t = \bot^d$ and t' is any type, where the following must hold $t' \neq \top^d$. From the definition of translation of \bot^d and the definition of strengthening operator, we get that that $t[\Gamma^d] = \bot^d$. Then, by the definition of translation we get $\tilde{\mathcal{T}}^t(t) = \bot^b$. Next, we consider the type structure of t'. If $t' = \bot^d$ or $t' = \beta'$, then the proof is immediate as the ordering holds in the domain of basic refinement types and we can apply S-BASE. If it's a function type case, we must have $t' = (x : t_1) \to (\varpi : \phi_1) \to t_2$, with its type translated backward to $\tilde{\mathcal{T}}^t(t') = x : \tilde{\mathcal{T}}^t(t_1) \& \phi \to \tilde{\mathcal{T}}^{te}(t_2)$. The rule is immediate following the premise that the function in the type and effect system is different from \top .

Case S-BASE[D] Follows immediately from lemma B.2, reductive property of strengthening and rule S-BASE

Case s-fun[d] We can have $t = (x:t_1) \to (\varpi:\phi_1) \to t_2$ and $t' = (x:t_1') \to (\varpi:\phi_1') \to t_2'$. From subtyping rule premises we get the proof that input type and effect are contravariant, and output type is covariant. We must have $t_1' <:^d t_1$, $\phi_1'[\Gamma^d, x:t_1'] <:^d \phi_1[\Gamma^d, x:t_1']$ and $t_2[\Gamma^d, x:t_1'] <:^d t_2'[\Gamma^d, x:t_1]$. We know that t_2 and t_2' are pair types and we can use the definition of strengthening that is applied component wise. Finally, we use the induction hypothesis and rule s-fun to conclude the proof.

Lemma B.5. For all backward translatable Γ^d , and effects ϕ, ϕ' , if $\phi[\Gamma^d] <: ^d \phi'[\Gamma^d]$ then $\phi[\tilde{\mathcal{T}}^t(\Gamma^d)] \sqsubseteq^{\phi} \phi'[\tilde{\mathcal{T}}^t(\Gamma^d)]$

PROOF. The proof is similar to the proof for B.4

We are now ready to prove the theorem 6.1

PROOF. The proof goes by structural induction. We show that we can inductively construct a derivation tree for a type and effect judgment of term e from the derivation trees of its subterms. We do this by considering each of the possible forms e can have. We use $\Gamma = \overline{\mathcal{T}}^t(\Gamma^d)$ in the following.

Case Const We have term e=c for some constant c such that, given a term ϖ with type ϕ , the translated term is $\mathcal{T}[[c]](\varpi) \stackrel{\text{def}}{=} \langle c, \varpi \rangle$ and $\Gamma^d, \varpi: \phi \vdash^d \langle c, \varpi \rangle: t$. By the fact that the translated term is a pair we must have a proof for T-PAIR[D], and $t=t_1 \times \phi'$ Using the typing rule T-PROJ[D] we retrieve the proofs for individual types $\Gamma^d, \varpi: \phi \vdash^d c: t_1$ and $\Gamma^d, \varpi: \phi \vdash^d \varpi: \phi'$ of each pair component.

By rule T-CONST[D] we know that the most precise type of c is $[v=c]^d[\Gamma^d,\varpi:\phi]$ and that t_1 must be a base refinement type. Let $\tau=\bar{\mathcal{T}}^t(t_1)$. By the definition of the backwards translation for types, $\tau\in\mathcal{B}$. From the definition of type semantics for constants we know that both $[v=c]^d$ and $\{v=c\}_{\mathcal{B}}$ are the most precise approximations of $\{c\}\times Env$, therefore they must be equal. Additionally, we know that $[v=c]^d[\Gamma^d,\varpi:\phi]=[v=c]^d[\Gamma^d]$ because by definition the strengthening with a type information for effects leaves unchanged the type that is strengthened, and $[v=c]^d[\Gamma^d]<:^dt_1$ from T-CONST[D]. Then by lemma B.4 and rule S-BASE we obtain that $\Gamma \vdash \{v=c\}_{\mathcal{B}}<:\tau$.

Next, we move to derive the effect ordering. From the rule T-VAR[D] we know that the following must hold $\phi[\nu=\varpi]^d[\Gamma^d,\varpi:\phi]^d<:\phi'[\nu=\varpi]^d[\Gamma^d,\varpi:\phi]^d$, that after eliminating the strengthening operation with ϕ is $\phi[\nu=\varpi]^d[\Gamma^d]^d<:\phi'[\nu=\varpi]^d[\Gamma^d]^d$. By lemma B.5 together with the commutativity and reductive properties of the strengthening operator, we get $\phi[\Gamma] \sqsubseteq^\phi \phi[\nu=\varpi][\Gamma] \sqsubseteq^\phi \phi'[\nu=\varpi][\Gamma] \sqsubseteq^\phi \phi'$, giving us $\phi[\Gamma^d] \sqsubseteq^\phi \phi'$. By the reductive property of the strengthening operation we also have $\phi[\Gamma] \sqsubseteq^\phi \phi$

We conclude the proof for Γ ; $\phi \vdash c : \tau \& \phi'$ by using T-WEAKEN together with T-CONST for constant c instantiated with typing environment Γ and effect ϕ , and using the proofs derived for $\phi[\Gamma] \sqsubseteq^{\phi} \phi$, $\Gamma \vdash \{v = c\}_{\mathcal{B}} <: \tau$ and $\phi[\Gamma] \sqsubseteq^{\phi} \phi'$.

Case Var We have term e = x for some x such that, given a term ϖ with type ϕ , the translated term is $\mathcal{T}[[x]](\varpi) \stackrel{\text{def}}{=} \langle x, \varpi \rangle$ and $\Gamma^d, \varpi : \phi \vdash^d \langle x, \varpi \rangle : t$. By the fact that the translated term is a pair we must have a proof for T-PAIR[D], and $t = t_1 \times \phi'$ We use again T-PROJ[D] for getting $\Gamma^d, \varpi : \phi \vdash^d x : t_1$ and $\Gamma^d, \varpi : \phi \vdash^d \varpi : \phi'$.

From the rule T-VAR[D] we know that the premise must hold $\Gamma^d(x)[\nu=x][\Gamma^d,\varpi:\phi]<:^dt_1[\nu=x][\Gamma^d,\varpi:\phi]$. We start by eliminating the strengthening with the ϕ type information in both sides of the subtyping relation. Let $\tau=\bar{\mathcal{T}}^t(t_1)$. Next, by lemma B.4 we get $\Gamma \vdash \Gamma(x)[\nu=x]<:\tau[\nu=x]$. We have $\Gamma(x)[\nu=x]=\Gamma(x)$ because x is a fresh variable and it doesn't restrict the values represented by the type variable ν . By the reductive property of strengthening we have $\Gamma \vdash \tau[\nu=x]<:\tau$. Therefore, we get $\Gamma \vdash \Gamma(x)<:\tau$. We get the proof that $\phi[\Gamma] \sqsubseteq^{\phi} \phi'$ and $\phi[\Gamma] \sqsubseteq^{\phi} \phi$ the same we did for Case e-var. We use again T-WEAKEN with T-VAR for variable x instantiated with typing environment Γ and effect ϕ , together with the proofs derived for $\phi[\Gamma] \sqsubseteq^{\phi} \phi$, $\Gamma \vdash \Gamma(x) <:\tau$ and $\phi[\Gamma] \sqsubseteq^{\phi} \phi'$ to conclude the proof.

Case Abs We have term $e = \lambda x.e_i$ such that, given a term ϖ with type ϕ , the translated term is $\mathcal{T}[[\lambda x.e_i]] = \langle \lambda x.\lambda \varpi_x.(\mathcal{T}[[e_i]](\varpi_x)), \varpi \rangle$, and $\Gamma^d, \varpi : \phi \vdash^d \langle \lambda x.\lambda \varpi_x.(\mathcal{T}[[e_i]](\varpi_x)), \varpi \rangle : t$. From the rules T-PAIR[D], T-PROJ[D] and T-ABS[D] used in derivation, and by induction hypothesis we get the derivations in the type and effect system for the following:

- $\dot{\tilde{T}}^{te}(t) = \tau \& \phi'$
- $\Gamma \vdash \lambda x.e_i : \tau$
- $\Gamma, x : \tau_x; \ \phi_x \vdash e_i : \tau_i \& \phi_i$
- $\Gamma \vdash (x : \tau_x \& \phi_x \to \tau_i \& \phi_i) <: \tau$.

Then following the subtyping judgment it must be that $\tau = x : \tau_x' \& \phi_x' \to \tau_i' \& \phi_i'$. The proof follows immediately from using B.4 several times to construct the subtyping judgments in the type and effect system and lastly T-WEAKEN after constructing a derivation for the effect in the same spirit as for the constant and variable expressions.

Case App We have term $e = e_1 \ e_2$ such that, given a term ϖ with type ϕ , the translated term is after desugaring the **let** constructs:

```
 \begin{array}{l} (\lambda e_{1}'.(\\ \lambda \varpi_{1}'.(\\ \lambda e_{2}'.(\\ \lambda \varpi_{2}'.(e_{1}'\ e_{2}')\ \varpi_{2}')\\ (\#_{2}(\mathcal{T}[[e_{2}]](\varpi_{1}')))\\ (\#_{1}(\mathcal{T}[[e_{2}]](\varpi_{1})))\\ (\#_{2}(\mathcal{T}[[e_{1}]](\varpi)))\\ (\#_{1}(\mathcal{T}[[e_{1}]](\varpi))) \end{array}
```

We know that Γ^d , $\varpi : \phi \vdash^d \mathcal{T}[[e_1 e_2]](\varpi) : t$, and we must have used the rule T-APP[D], therefore we know that Γ^d , $\omega: \phi \vdash^d \mathcal{T}[[e_1]](\omega): t_1$ and Γ^d , $e'_1: t'_1, \omega'_1: \phi_1 \vdash^d \mathcal{T}[[e_2]](\omega'_1): t_2$ and $t_1 <: ^d x : t_2 \to t$. By induction hypothesis we know that $\Gamma^d, \varpi : \phi \vdash^d \mathcal{T}[[e_1]](\varpi) :$ $t_1 \Rightarrow \Gamma; \phi \vdash e_1 : \tilde{\mathcal{T}}^{te}(t_1)$. Let $\tilde{\mathcal{T}}^{te}(t_1) = \tau_1 \times \phi_1$. It is immediate to see that, if in the type and effect system the following holds $\Gamma \vdash \tau_1 <: \tau_2$, then we can always show that for any $x:\tau_x$, the subtyping is preserved $\Gamma, x:\tau_x + \tau_1 <: \tau_2$ (by monotonicity of strengthening operator). Using lemma B.4 we can construct from the subtyping derivation of $\lambda e'_1, \ldots$ we get from the premise of T-APP[D] a subtyping derivation. In our type and effect system the subtyping will hold in an empty typing environment. Because the strengthening operator is reductive, we can always introduce new type bindings in the context while maintaining the subtyping relation. We do that repeatedly until we can construct a proof for the subtyping with the same typing environment as used in for the expression $\#_1(\mathcal{T}[e_1](\varpi))$. Then we obtain the existential type by the reflexivity of subtyping followed by the derivation we can construct in the type and effect system using the introduction of a new type binding, and by the application of rule S-EXISTS. While long and cumbersome, the proof follows from applying the same strategy multiple times and then the rule T-APP to construct the typing derivation for the application.

Case EV The proof is immediate by using rules T-EXTENSION-OP[D] and the type operator ⊙ provided by the abstract effect domain.

C CPS TRANSLATION OF EXAMPLE 2.1

```
1 let main prefx prefn =
    let ev = fun k0 q acc evx ->
              if (q = 0) then k0 1 evx ()
              else if ((q = 1) \&\& ((acc + evx) = 0)) then k0 2 acc ()
5
                   else if (q = 2) then k0 2 acc ()
                       else k0 q acc () in
    let q1 = 0 in
    let acc1 = 0 in
    let f0 = fun k4 q3 acc3 busy ->
              let f1 = fun k6 q5 acc5 _main ->
                        let k8 q7 acc7 res3 =
                          let k7 q6 acc6 res2 =
                            k6 q6 acc6 res2 in
13
                          res3 k7 q7 acc7 prefn in
14
                        _main k8 q5 acc5 prefx in
              let f2 = fun k9 q8 acc8 x ->
                        let f3 = fun k10 q9 acc9 n ->
                                  let x3 = () in
18
                                  let k11 q10 acc10 x2 =
                                    let k13 q12 acc12 res5 =
20
                                      let k12 q11 acc11 res4 =
                                        let x1 = x3; res4 in k10 q11 acc11 x1 in
                                      res5 k12 q12 acc12 x in
23
                                    busy k13 q10 acc10 n in
24
```

```
ev k11 q9 acc9 x in
25
                        k9 q8 acc8 f3 in
26
              let k5 q4 acc4 res1 =
                k4 q4 acc4 res1 in
28
              f1 k5 q3 acc3 f2 in
29
    let rec busy k14 q13 acc13 n =
30
      let f4 = fun k15 q14 acc14 t ->
                let x5 = 0 in
32
                let x4 = n \le x5 in
                let k16 q15 acc15 res6 =
34
                  k15 q15 acc15 res6 in
35
                let k17 q16 acc16 res7 =
36
                  let x11 = -t in let x10 = () in
37
                                   let k21 q20 acc20 x9 =
38
                                     let x12 = 0 in
39
                                     let x8 = x10; x12 in k16 q20 acc20 x8 in
40
                                   ev k21 q16 acc16 x11 in
41
42
                let k18 q17 acc17 res8 =
                  let x7 = 1 in
                  let x6 = n - x7 in let k20 q19 acc19 res10 =
44
                                       let k19 q18 acc18 res9 =
45
                                         k16 q18 acc18 res9 in
46
                                       res10 k19 q19 acc19 t in
                                     busy k20 q17 acc17 x6 in
48
                if x4 then k17 q14 acc14 x4 else k18 q14 acc14 x4 in
49
      k14 q13 acc13 f4 in
    let k3 q2 acc2 res0 =
51
52
     let k22 q acc x13 =
        let x15 = 2 in
       let x14 = q = x15 in assert(x14); x13 in
     k22 q2 acc2 res0 in
    f0 k3 q1 acc1 busy
```

D EXTENDED EVALUATION

Configurations. T=he following table lists all configurations we used for DRIFT and ev-DRIFT:

Tool	Trace Len.	Trace Part.	Threshold	
Drift	0	false	false	PolkaGrid
Drift	0	false	true	Polka (Loose)
Drift	0	false	true	Polka (Strict)
Drift	0	false	true	Octogon
Drift	1	true	false	PolkaGrid
Drift	1	true	true	Polka (Loose)
Drift	1	true	true	Polka (Strict)
Drift	1	true	true	Octogon
Drift	1	false	false	PolkaGrid
Drift	1	false	true	Polka (Loose)
Drift	1	false	true	Polka (Strict)
Drift	1	false	true	Octogon
ev-Drift	0	false	false	PolkaGrid
ev-Drift	0	false	true	Polka (Loose)
ev-Drift	0	false	true	Polka (Strict)
ev-Drift	0	false	true	Octogon
ev-Drift	1	true	false	PolkaGrid
ev-Drift	1	true	true	Polka (Loose)
ev-Drift	1	true	true	Polka (Strict)
ev-Drift	1	true	true	Octogon
ev-Drift	1	false	false	PolkaGrid
ev-Drift	1	false	true	Polka (Loose)
ev-Drift	1	false	true	Polka (Strict)
ev-Drift	1	false	true	Octogon
		•	•	

Full experiments. The following table lists all results from running RCaml/PCSat, Drift and ${\bf ev}$ Drift on all configurations.

Bench	Res	CPU	Mem	Config	
1. all-ev-pos					
	Drift	$\langle tl:0, tp:F, th:T, ls \rangle$	~	2.61	
	Drift	$\langle tl:1, tp:T, th:F, pg \rangle$	~	44.83	29.90
	Drift	$\langle tl:1, tp:F, th:F, pg \rangle$?	40.63	28.37
	Drift	$\langle tl:1, tp:T, th:T, oct \rangle$	~	12.71	50.26
	Drift	$\langle tl:1, tp:F, th:T, oct \rangle$	~	9.90	44.68
	Drift	$\langle tl:0, tp:F, th:T, oct \rangle$	~	4.86	37.02
	Drift	$\langle tl:0, tp:F, th:F, pg \rangle$?	14.31	17.01
	Drift	$\langle tl:0, tp:F, th:T, st \rangle$		2.96	24.16
	Drift	$\langle tl:1, tp:F, th:T, st \rangle$	~	6.12	23.26
	Drift	$\langle tl:1, tp:T, th:T, ls \rangle$	~	6.87	21.11
	Drift	$\langle tl:1, tp:T, th:T, st \rangle$	~	8.02	24.17
	Drift	$\langle tl:1, tp:F, th:T, ls \rangle$	~	5.26	20.11
	evDrift		~	0.18	9.46
	evDrift	$\langle tl:1, tp:F, th:T, oct \rangle$	~	0.66	11.29
	evDrift		~	2.36	12.12
	evDrift		~	0.76	12.64
	evDrift		~	0.57	10.29
	evDrift	$\langle tl:0, tp:F, th:T, oct \rangle$	~	0.17	8.81
	evDrift		?	0.81	10.35
	evDrift	$\langle tl:1, tp:F, th:T, st \rangle$	~	0.70	12.65
		$\langle tl:1, tp:T, th:T, oct \rangle$	~	0.70	11.22
	evDrift		~	2.05	12.05
	evDrift		~	0.16	8.41
	ev Drift	$\langle tl:1, tp:T, th:T, ls \rangle$	~	0.62	10.01
2. auction					
	Drift	$\langle tl:0, tp:F, th:T, ls \rangle$	M		1000.00
	Drift	$\langle tl:1, tp:F, th:F, pg \rangle$?	197.12	62.85
	Drift	$\langle tl:1, tp:T, th:F, pg \rangle$?	254.03	68.49
	Drift	$\langle tl:0, tp:F, th:T, st \rangle$	M		1000.00
	Drift	$\langle tl:0, tp:F, th:T, oct \rangle$?	162.59	241.06
	Drift	$\langle tl:1, tp:F, th:T, oct \rangle$?	244.29	
	Drift	$\langle tl:0, tp:F, th:F, pg \rangle$?	98.81	38.03
	Drift	$\langle tl:1, tp:T, th:T, oct \rangle$?	271.24	368.71
	Drift	$\langle tl:1, tp:T, th:T, ls \rangle$?	145.65	62.99
	Drift	$\langle tl:1, tp:F, th:T, st \rangle$?	180.57	136.26
	Drift	$\langle tl:1, tp:F, th:T, ls \rangle$? ? ? ? ? ? ?	138.82	107.26
	Drift	$\langle tl:1, tp:T, th:T, st \rangle$?	180.22	82.60
	evDrift	$\langle tl:0, tp:F, th:T, st \rangle$?	1.73	22.49
		$\langle tl:1, tp:F, th:T, oct \rangle$?	3.17	21.56
		$\langle tl:1, tp:T, th:F, pg \rangle$	V	2.75	12.59
	ev Drift	$\langle tl:1, tp:F, th:T, ls \rangle$	~	1.63	15.86

2 hiamia) haan	evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift	$ \begin{array}{c} \langle tl:0,tp:F,th:F,pg\rangle \\ \langle tl:1,tp:T,th:T,ls\rangle \\ \langle tl:0,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:T,th:T,oct\rangle \\ \langle tl:1,tp:F,th:F,pg\rangle \end{array} $	> ? ? ? > Y	2.11 2.09 1.34 1.72 1.34 3.29 2.68 1.99	20.03 16.13 10.92 15.83 16.06 22.62 12.32 19.39
3. binomial_heap	DRIFT EVDRIFT	$ \begin{array}{l} \langle tl:1, tp:T, th:T, oct \rangle \\ \langle tl:1, tp:F, th:T, st \rangle \\ \langle tl:1, tp:F, th:T, st \rangle \\ \langle tl:0, tp:F, th:T, ls \rangle \\ \langle tl:0, tp:F, th:T, ls \rangle \\ \langle tl:0, tp:F, th:T, oct \rangle \\ \langle tl:1, tp:F, th:T, ls \rangle \\ \langle tl:1, tp:F, th:T, st \rangle \\ \langle tl:1, tp:T, th:F, pg \rangle \\ \langle tl:1, tp:F, th:T, st \rangle \\ \langle tl:1, tp:F, th:T, oct \rangle \\ \langle tl:1, tp:F, th:T, oct \rangle \\ \end{array} $	**************************************	0.10 0.09 0.10 0.09 0.23 0.16 0.43 0.25 0.33 0.24 0.13 11.72 14.91 7.32 6.39 11.52 10.44 6.55 7.47 11.73 14.67	11.82 10.76 11.98 10.79 14.87 17.28 11.45 15.39 23.49 10.61 10.49 15.44 18.35 60.19 34.26 28.37 40.67 16.43 56.28 29.00 32.17 77.69 63.21
4. depend	DRIFT EVDRIFT	\(\langle t 0, tp:F, th:T, st\) \(\langle t 0, tp:F, th:F, pg\) \(\langle t 1, tp:F, th:T, oct\) \(\langle t 1, tp:F, th:F, pg\) \(\langle t 1, tp:F, th:T, ls\) \(\langle t 1, tp:F, th:T, ls\) \(\langle t 1, tp:F, th:T, st\) \(\langle t 1, tp:F, th:T, ls\) \(\langle t 1, tp:F, th:T, st\) \(\langle t 1, tp:F, th:T, st\)	***************************************	7.52 0.19 0.60 0.26 0.29 0.29 0.16 0.11 0.13 0.11 0.12 0.02 0.02 0.04 0.02 0.02 0.02 0.02 0.0	57.31 12.35 10.52 10.53 14.09 10.64 8.61 9.77 8.65 9.66 5.04 5.66 6.98 5.54 5.93 5.18 5.04 6.86 5.93 5.18 5.92 5.55 6.86 5.93
5. disj		$ \begin{cases} \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : T, ls \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \end{cases} $	T T ? ? ? ? ? ? T T ?	900.36 900.33 102.85 900.25 157.48 666.44 314.94 360.77 338.24 900.25 930.99 205.94 22.47 8.90	164.26 163.08 1000.00 379.10 77.18 487.00 285.73 279.24 283.46 220.73 199.95 26.89

	evDrift	$\langle tl:0, tp:F, th:T, st \rangle$?	3.67	52.68
	_		?		
	evDrift	$\langle tl:1, tp:F, th:T, ls \rangle$		5.12	39.45
	evDrift	$\langle tl:1, tp:T, th:T, st \rangle$?	12.65	43.91
	ev Drift		1	9.61	21.32
	evDrift		?	6.37	105.95
	_				
	evDrift	$\langle tl:1, tp:F, th:F, pg \rangle$	~	16.15	23.78
	ev Drift	$\langle tl:1, tp:T, th:T, oct \rangle$?	16.76	91.13
	evDrift	$\langle tl:1, tp:F, th:T, st \rangle$	2	5.74	44.43
			?		
	evDrift	$\langle tl:1, tp:T, th:T, ls \rangle$		11.41	38.92
	ev Drift	$\langle tl:0, tp:F, th:T, ls \rangle$?	3.26	46.26
6. disj-gte					
8	Drift	$\langle tl:1, tp:F, th:T, ls \rangle$?	347.98	205.54
	I_				
	Drift	$\langle tl:1, tp:T, th:T, st \rangle$	~	380.58	167.01
	Drift	$\langle tl:1, tp:T, th:T, ls \rangle$	~	343.71	153.18
	Drift	$\langle tl:1, tp:F, th:T, st \rangle$?	519.21	288.56
	I_		?		
	DRIFT	$\langle tl:1, tp:F, th:T, oct \rangle$		698.02	264.17
	Drift	$ \langle tl:0, tp:F, th:T, oct \rangle $?	420.59	528.92
	Drift	$\langle tl:0, tp:F, th:F, pq \rangle$	T	900.24	91.66
	Drift	$\langle tl:0, tp:F, th:T, st \rangle$?	226.52	353.47
	I_				
	Drift	$\langle tl:1, tp:T, th:T, oct \rangle$	T	900.25	
	Drift	$\langle tl:0,tp:F,th:T,ls\rangle$?	145.96	223.59
	Drift	$\langle tl:1, tp:T, th:F, pq \rangle$	T	900.25	171.26
	DRIFT	$\langle tl:1, tp:F, th:F, pq \rangle$	Ť	900.25	139.80
	_	\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\			
	evDrift	$\langle tl:0, tp:F, th:T, ls \rangle$?_	5.14	42.87
	ev Drift	$\langle tl:1, tp:T, th:T, ls \rangle$	~	7.63	26.75
	evDrift	$\langle tl:1, tp:F, th:T, st \rangle$	1	7.22	31.87
	_				
	evDrift		V	11.00	59.38
	evDrift	$\langle tl:1, tp:F, th:F, pg \rangle$	~	25.88	27.30
	ev Drift	$\langle tl:0, tp:F, th:T, oct \rangle$?	7.90	81.28
	evDrift	$\langle tl:0,tp:F,th:F,pq\rangle$?	36.99	30.22
	_				
	evDrift	$\langle tl:1, tp:T, th:T, st \rangle$	1	8.67	30.18
	evDrift	$\langle tl:1, tp:F, th:T, ls \rangle$	~	6.42	28.07
	ev Drift	$\langle tl:1, tp:F, th:T, oct \rangle$	~	9.89	62.48
	evDrift	$\langle tl:0, tp:F, th:T, st \rangle$?	5.52	47.19
	evDrift	$\langle tl:1, tp:T, th:F, pg \rangle$	~	26.88	28.45
7. higher-order				_	
	Drift	$\langle tl:1, tp:F, th:T, ls \rangle$	~	28.92	34.37
	Drift	$\langle tl:1, tp:T, th:T, st \rangle$	1	40.22	38.95
	I_		V		
	Drift	$\langle tl:1, tp:T, th:T, ls \rangle$		35.51	35.17
	Drift	$\langle tl:1, tp:F, th:T, st \rangle$	~	33.35	38.84
	Drift	$\langle tl:0, tp:F, th:F, pq \rangle$?	86.62	28.82
	Drift	$\langle tl:0, tp:F, th:T, oct \rangle$?	50.19	127.17
	Drift	$\langle tl:1, tp:F, th:T, oct \rangle$	~	69.81	171.02
	Drift	$\langle tl:0, tp:F, th:T, st \rangle$?	29.90	83.69
	Drift	$\langle tl:1, tp:T, th:T, oct \rangle$	~	86.29	195.62
	Drift	$\langle tl:1, tp:F, th:F, pq \rangle$	2	205.65	49.89
			?		
	Drift	$\langle tl:1, tp:T, th:F, pq \rangle$			
				133.49	47.77
	Drift	$\langle tl:0,tp:F,th:T,ls\rangle$?	21.65	47.77 74.85
			?	21.65	74.85
	ev Drift	$\langle tl:0, tp:F, th:T, ls \rangle$?	21.65 0.59	74.85 12.62
	evDrift evDrift	$\langle tl:0, tp:F, th:T, ls \rangle$ $\langle tl:1, tp:T, th:T, ls \rangle$?	21.65 0.59 1.15	74.85 12.62 12.48
	evDrift evDrift evDrift	$\langle tl:0, tp:F, th:T, ls \rangle$ $\langle tl:1, tp:T, th:T, ls \rangle$ $\langle tl:1, tp:F, th:T, st \rangle$? > > > > > > > > > > > > > > > > > > >	21.65 0.59 1.15 1.33	74.85 12.62 12.48 15.01
	evDrift evDrift	$\langle tl:0,tp:F,th:T,ls \rangle$ $\langle tl:1,tp:T,th:T,ls \rangle$ $\langle tl:1,tp:F,th:T,st \rangle$ $\langle tl:1,tp:F,th:F,pg \rangle$?ソソソ	21.65 0.59 1.15	74.85 12.62 12.48
	evDrift evDrift evDrift	$\langle tl:0, tp:F, th:T, ls \rangle$ $\langle tl:1, tp:T, th:T, ls \rangle$ $\langle tl:1, tp:F, th:T, st \rangle$? ソソソソ	21.65 0.59 1.15 1.33	74.85 12.62 12.48 15.01
	evDrift evDrift evDrift evDrift evDrift	$ \begin{array}{c} \langle tl:0,tp:F,th:T,ls \rangle \\ \langle tl:1,tp:T,th:T,ls \rangle \\ \langle tl:1,tp:F,th:T,st \rangle \\ \langle tl:1,tp:F,th:F,pg \rangle \\ \langle tl:1,tp:T,th:T,oct \rangle \end{array} $? ソソソソ	21.65 0.59 1.15 1.33 4.88 2.04	74.85 12.62 12.48 15.01 14.00 17.36
	evDrift evDrift evDrift evDrift evDrift evDrift	$\langle tl:0, tp:F, th:T, ls \rangle$ $\langle tl:1, tp:T, th:T, ls \rangle$ $\langle tl:1, tp:F, th:T, st \rangle$ $\langle tl:1, tp:F, th:F, pg \rangle$ $\langle tl:1, tp:T, th:T, oct \rangle$ $\langle tl:0, tp:F, th:F, pg \rangle$?ソソソソソ	21.65 0.59 1.15 1.33 4.88 2.04 1.95	74.85 12.62 12.48 15.01 14.00 17.36 11.63
	evDrift evDrift evDrift evDrift evDrift evDrift evDrift	$ \begin{array}{l} \langle tl : 0, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : T, oct \rangle \\ \end{array} $?ソソソソソ	21.65 0.59 1.15 1.33 4.88 2.04 1.95 0.84	74.85 12.62 12.48 15.01 14.00 17.36 11.63 14.54
	evDrift evDrift evDrift evDrift evDrift evDrift	$\langle tl:0, tp:F, th:T, ls \rangle$ $\langle tl:1, tp:T, th:T, ls \rangle$ $\langle tl:1, tp:F, th:T, st \rangle$ $\langle tl:1, tp:F, th:F, pg \rangle$ $\langle tl:1, tp:T, th:T, oct \rangle$ $\langle tl:0, tp:F, th:F, pg \rangle$	ペンンンンンン	21.65 0.59 1.15 1.33 4.88 2.04 1.95	74.85 12.62 12.48 15.01 14.00 17.36 11.63
	evDrift evDrift evDrift evDrift evDrift evDrift evDrift	$ \begin{aligned} &\langle tl:0,tp:F,th:T,ls\rangle \\ &\langle tl:1,tp:T,th:T,ls\rangle \\ &\langle tl:1,tp:F,th:T,st\rangle \\ &\langle tl:1,tp:F,th:F,pg\rangle \\ &\langle tl:1,tp:F,th:F,pg\rangle \\ &\langle tl:1,tp:F,th:F,pg\rangle \\ &\langle tl:0,tp:F,th:F,pg\rangle \\ &\langle tl:0,tp:F,th:T,oct\rangle \\ &\langle tl:1,tp:T,th:T,st\rangle \end{aligned} $	ペンンンンンン	21.65 0.59 1.15 1.33 4.88 2.04 1.95 0.84	74.85 12.62 12.48 15.01 14.00 17.36 11.63 14.54
	evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift	$ \begin{aligned} &\langle tl:0,tp:F,th:T,ls\rangle\\ &\langle tl:1,tp:T,th:T,ls\rangle\\ &\langle tl:1,tp:F,th:T,st\rangle\\ &\langle tl:1,tp:F,th:F,pg\rangle\\ &\langle tl:1,tp:T,th:T,oct\rangle\\ &\langle tl:0,tp:F,th:F,pg\rangle\\ &\langle tl:0,tp:F,th:T,oct\rangle\\ &\langle tl:1,tp:T,th:T,st\rangle\\ &\langle tl:1,tp:T,th:T,st\rangle\\ &\langle tl:1,tp:T,th:T,ls\rangle \end{aligned}$?ソソソソソ	21.65 0.59 1.15 1.33 4.88 2.04 1.95 0.84 1.37 1.13	74.85 12.62 12.48 15.01 14.00 17.36 11.63 14.54 14.71 12.91
	evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift	$ \begin{array}{l} \langle tl : 0, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : F, pg \rangle \\ \end{array} $? > > > > > > > > > > > > > > > > > > >	21.65 0.59 1.15 1.33 4.88 2.04 1.95 0.84 1.37 1.13 4.92	74.85 12.62 12.48 15.01 14.00 17.36 11.63 14.54 14.71 12.91 13.73
	evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift	$ \begin{array}{l} \langle tl : 0, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \end{array} $? > > > > > > > > > > > > > > > > > > >	21.65 0.59 1.15 1.33 4.88 2.04 1.95 0.84 1.37 1.13 4.92 1.98	74.85 12.62 12.48 15.01 14.00 17.36 11.63 14.54 14.71 12.91 13.73 17.14
	evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift	$ \begin{array}{l} \langle tl : 0, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : F, pg \rangle \\ \end{array} $? > > > > > > > > > > > > > > > > > > >	21.65 0.59 1.15 1.33 4.88 2.04 1.95 0.84 1.37 1.13 4.92	74.85 12.62 12.48 15.01 14.00 17.36 11.63 14.54 14.71 12.91 13.73
8. last-ev-even	evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift	$ \begin{aligned} &\langle tl : 0, tp : F, th : T, ls \rangle \\ &\langle tl : 1, tp : T, th : T, ls \rangle \\ &\langle tl : 1, tp : F, th : T, st \rangle \\ &\langle tl : 1, tp : F, th : F, sp \rangle \\ &\langle tl : 1, tp : F, th : F, pg \rangle \\ &\langle tl : 0, tp : F, th : F, pg \rangle \\ &\langle tl : 0, tp : F, th : T, oct \rangle \\ &\langle tl : 1, tp : T, th : T, st \rangle \\ &\langle tl : 1, tp : T, th : T, st \rangle \\ &\langle tl : 1, tp : F, th : T, ls \rangle \\ &\langle tl : 1, tp : F, th : T, oct \rangle \\ &\langle tl : 0, tp : F, th : T, st \rangle \end{aligned} $?	21.65 0.59 1.15 1.33 4.88 2.04 1.95 0.84 1.37 1.13 4.92 1.98 0.68	74.85 12.62 12.48 15.01 14.00 17.36 11.63 14.54 14.71 12.91 13.73 17.14 15.01
8. last-ev-even	evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift	$ \begin{array}{l} \langle tl : 0, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \end{array} $?	21.65 0.59 1.15 1.33 4.88 2.04 1.95 0.84 1.37 1.13 4.92 1.98	74.85 12.62 12.48 15.01 14.00 17.36 11.63 14.54 14.71 12.91 13.73 17.14 15.01
8. last-ev-even	evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift	$ \begin{array}{c} \langle tl : 0, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : F, pg \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \end{array} $?	21.65 0.59 1.15 1.33 4.88 2.04 1.95 0.84 1.37 1.13 4.92 1.98 0.68	74.85 12.62 12.48 15.01 14.00 17.36 11.63 14.54 14.71 12.91 13.73 17.14 15.01
8. last-ev-even	evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift Drift Drift	$ \begin{aligned} &\langle tl:0,tp:F,th:T,ls\rangle \\ &\langle tl:1,tp:T,th:T,ls\rangle \\ &\langle tl:1,tp:F,th:T,st\rangle \\ &\langle tl:1,tp:F,th:F,st\rangle \\ &\langle tl:1,tp:F,th:F,pg\rangle \\ &\langle tl:1,tp:F,th:F,pg\rangle \\ &\langle tl:0,tp:F,th:F,pg\rangle \\ &\langle tl:0,tp:F,th:T,oct\rangle \\ &\langle tl:1,tp:T,th:T,st\rangle \\ &\langle tl:1,tp:T,th:T,ls\rangle \\ &\langle tl:1,tp:F,th:T,ls\rangle \\ &\langle tl:1,tp:F,th:T,ls\rangle \\ &\langle tl:1,tp:F,th:T,st\rangle \\ &\langle tl:1,tp:F,th:T,st\rangle \\ &\langle tl:1,tp:F,th:T,st\rangle \\ &\langle tl:1,tp:F,th:T,st\rangle \\ \end{aligned}$?	21.65 0.59 1.15 1.33 4.88 2.04 1.95 0.84 1.37 1.13 4.92 1.98 0.68 46.35 86.08	74.85 12.62 12.48 15.01 14.00 17.36 11.63 14.54 14.71 12.91 13.73 17.14 15.01 47.67 57.33
8. last-ev-even	evDRIFT DRIFT DRIFT DRIFT DRIFT	$ \begin{aligned} &\langle tl: 0, tp:F, th:T, ls \rangle \\ &\langle tl: 1, tp:T, th:T, ls \rangle \\ &\langle tl: 1, tp:F, th:T, st \rangle \\ &\langle tl: 1, tp:F, th:F, st \rangle \\ &\langle tl: 1, tp:F, th:F, pg \rangle \\ &\langle tl: 1, tp:F, th:F, pg \rangle \\ &\langle tl: 0, tp:F, th:T, oct \rangle \\ &\langle tl: 0, tp:F, th:T, st \rangle \\ &\langle tl: 1, tp:T, th:T, st \rangle \\ &\langle tl: 1, tp:F, th:T, ls \rangle \\ &\langle tl: 1, tp:F, th:T, st \rangle \end{aligned} $?	21.65 0.59 1.15 1.33 4.88 2.04 1.95 0.84 1.37 1.13 4.92 1.98 0.68 46.35 86.08 97.85	74.85 12.62 12.48 15.01 14.00 17.36 11.63 14.54 14.71 12.91 13.73 17.14 15.01 47.67 57.33 64.64
8. last-ev-even	evDRIFT DRIFT DRIFT DRIFT DRIFT	\(\lambda(t):0, \(\dagger p:F, th:T, ls\rangle\)\(\lambda(t):1, tp:T, th:T, ls\rangle\)\(\lambda(t):1, tp:F, th:F, st\rangle\)\(\lambda(t):1, tp:F, th:F, pg\rangle\)\(\lambda(t):0, tp:F, th:T, oct\rangle\)\(\lambda(t):0, tp:F, th:T, st\rangle\)\(\lambda(t):1, tp:T, th:T, st\rangle\)\(\lambda(t):1, tp:F, th:T, ls\rangle\)\(\lambda(t):1, tp:F, th:T, oct\rangle\)\(\lambda(t):1, tp:F, th:T, st\rangle\)\(\lambda(t):1, tp:F, th:T, st\rangle\)\(\lambda(t):1, tp:F, th:T, st\rangle\)\(\lambda(t):1, tp:T, th:T, st\rangle\)\(\lambda(t):1, tp:F, th:T, ls\rangle\)	?	21.65 0.59 1.15 1.33 4.88 2.04 1.95 0.84 1.37 1.13 4.92 1.98 0.68 46.35 86.08 97.85 39.82	74.85 12.62 12.48 15.01 14.00 17.36 11.63 14.54 14.71 12.91 13.73 17.14 15.01 47.67 57.33 64.64 42.19
8. last-ev-even	evDRIFT DRIFT DRIFT DRIFT DRIFT	$ \begin{array}{l} \langle tl : 0, fp : F, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : F, sp \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle $?	21.65 0.59 1.15 1.33 4.88 2.04 1.95 0.84 1.37 1.13 4.92 1.98 0.68 46.35 86.08 97.85	74.85 12.62 12.48 15.01 14.00 17.36 11.63 14.54 14.71 12.91 13.73 17.14 15.01 47.67 57.33 64.64 42.19 37.96
8. last-ev-even	evDRIFT DRIFT DRIFT DRIFT DRIFT	\(\lambda(t):0, \(\dagger p:F, th:T, ls\rangle\)\(\lambda(t):1, tp:T, th:T, ls\rangle\)\(\lambda(t):1, tp:F, th:F, st\rangle\)\(\lambda(t):1, tp:F, th:F, pg\rangle\)\(\lambda(t):0, tp:F, th:T, oct\rangle\)\(\lambda(t):0, tp:F, th:T, st\rangle\)\(\lambda(t):1, tp:T, th:T, st\rangle\)\(\lambda(t):1, tp:F, th:T, ls\rangle\)\(\lambda(t):1, tp:F, th:T, oct\rangle\)\(\lambda(t):1, tp:F, th:T, st\rangle\)\(\lambda(t):1, tp:F, th:T, st\rangle\)\(\lambda(t):1, tp:F, th:T, st\rangle\)\(\lambda(t):1, tp:T, th:T, st\rangle\)\(\lambda(t):1, tp:F, th:T, ls\rangle\)	?	21.65 0.59 1.15 1.33 4.88 2.04 1.95 0.84 1.37 1.13 4.92 1.98 0.68 46.35 86.08 97.85 39.82	74.85 12.62 12.48 15.01 14.00 17.36 11.63 14.54 14.71 12.91 13.73 17.14 15.01 47.67 57.33 64.64 42.19
8. last-ev-even	evDrift Drift Drift Drift Drift Drift Drift Drift	$ \begin{array}{l} \langle tl : 0, fp : F, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, pg \rangle \\ \end{array}$?	21.65 0.59 1.15 1.33 4.88 2.04 1.95 0.84 1.37 1.13 4.92 1.98 0.68 46.35 86.08 97.85 39.82 11.62 341.43	74.85 12.62 12.48 15.01 14.00 17.36 11.63 14.54 14.71 12.91 13.73 17.14 15.01 47.67 57.33 64.64 42.19 37.96 86.47
8. last-ev-even	evDrift Drift Drift Drift Drift Drift Drift Drift Drift	$ \begin{array}{l} \langle tl:0,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:T,th:T,ls\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:F,st\rangle \\ \langle tl:1,tp:F,th:F,pg\rangle \\ \langle tl:1,tp:F,th:F,pg\rangle \\ \langle tl:0,tp:F,th:F,oct\rangle \\ \langle tl:0,tp:F,th:T,oct\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,ss\rangle \\ \langle tl:1,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:F,th:F,pg\rangle \\ \langle tl:1,tp:F,th:F,th:F,pg\rangle \\ \langle tl:1,tp:F,th:F,th:F,pg\rangle \\ \langle tl:1,tp:F,th:F,th:F,th:F,th:F,th:F,th:F,th:F,th$?	21.65 0.59 1.15 1.33 4.88 2.04 1.95 0.84 1.37 1.13 4.92 1.98 0.68 46.35 86.08 97.85 39.82 11.62 341.43 158.71	74.85 12.62 12.48 15.01 14.00 17.36 11.63 14.54 14.71 12.91 13.73 17.14 15.01 47.67 57.33 64.64 42.19 37.96 86.47 58.20
8. last-ev-even	evDRIFT DRIFT DRIFT DRIFT DRIFT DRIFT DRIFT DRIFT DRIFT DRIFT	$ \begin{array}{l} \langle tl : 0, fp : F, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : F, sp \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : F, oct \rangle \\ \langle tl : 0, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : T, oct \rangle \end{array} $?	21.65 0.59 1.15 1.33 4.88 2.04 1.95 0.84 1.37 1.13 4.92 1.98 0.68 46.35 86.08 97.85 39.82 11.62 341.43 158.71 132.34	74.85 12.62 12.48 15.01 14.00 17.36 11.63 14.54 14.71 12.91 13.73 17.14 15.01 47.67 57.33 64.64 42.19 37.96 86.47 58.20 277.23
8. last-ev-even	evDRIFT DRIFT	\(\lambda(t)\). \(\lambda(p)\). \(\text{F}\). \(th\). \(\lambda(t)\). \(\text{t}\). \(?	21.65 0.59 1.15 1.33 4.88 2.04 1.95 0.84 1.37 1.13 4.92 1.98 0.68 46.35 86.08 97.85 39.82 11.62 341.43 158.71 132.34 74.51	74.85 12.62 12.48 15.01 14.00 17.36 11.63 14.54 14.71 12.91 13.73 17.14 15.01 47.67 57.33 64.64 42.19 37.96 86.47 58.20 277.23 181.04
8. last-ev-even	evDRIFT DRIFT DRIFT DRIFT DRIFT DRIFT DRIFT DRIFT DRIFT DRIFT	\(\lambda(t)\). \(\lambda(p)\). \(\text{F}\). \(\text{t}\). \(\text{t}\)	?	21.65 0.59 1.15 1.33 4.88 2.04 1.37 1.13 4.92 1.98 0.68 46.35 86.08 97.85 39.82 11.62 341.43 158.71 132.34 74.51 34.18	74.85 12.62 12.48 15.01 14.00 17.36 11.63 14.54 14.71 12.91 13.73 17.14 15.01 47.67 57.33 64.64 42.19 37.96 86.47 58.20 277.23 181.04 91.41
8. last-ev-even	evDRIFT DRIFT	$ \begin{array}{l} \langle tl:0, fp:F, th:T, ls \rangle \\ \langle tl:1, tp:T, th:T, ls \rangle \\ \langle tl:1, tp:F, th:T, st \rangle \\ \langle tl:1, tp:F, th:F, sp \rangle \\ \langle tl:1, tp:F, th:F, pg \rangle \\ \langle tl:1, tp:F, th:F, pg \rangle \\ \langle tl:0, tp:F, th:T, oct \rangle \\ \langle tl:0, tp:F, th:T, oct \rangle \\ \langle tl:1, tp:T, th:T, st \rangle \\ \langle tl:1, tp:T, th:T, st \rangle \\ \langle tl:1, tp:F, th:T, ls \rangle \\ \langle tl:1, tp:F, th:T, st \rangle \\ \langle tl:1, tp:F, th:T, ls \rangle \\ \langle tl:1, tp:F, th:T, ls \rangle \\ \langle tl:1, tp:F, th:T, ls \rangle \\ \langle tl:1, tp:F, th:F, pg \rangle \\ \langle tl:1, tp:F, th:F, pg \rangle \\ \langle tl:1, tp:F, th:T, oct \rangle \\ \langle tl:1, tp:F, th:T, oct \rangle \\ \langle tl:0, tp:F, th:F, pg \rangle \\ \langle tl:0, tp:F, th:F, pg \rangle \\ \langle tl:0, tp:F, th:T, oct \rangle \\ \langle tl:0, tp:F, th:F, pg \rangle \\ \langle tl:0, tp:F, th:F, tp:F, tp:$?	21.65 0.59 1.15 1.33 4.88 2.04 1.95 0.84 1.37 1.13 4.92 1.98 0.68 46.35 86.08 97.85 39.82 11.62 341.43 158.71 132.34 74.51	74.85 12.62 12.48 15.01 14.00 17.36 11.63 14.54 14.71 12.91 13.73 17.14 15.01 47.67 57.33 64.64 42.19 37.96 86.47 58.20 277.23 181.04
8. last-ev-even	evDrift brift Drift	$ \begin{array}{l} \langle tl:0, fp:F, th:T, ls \rangle \\ \langle tl:1, tp:T, th:T, ls \rangle \\ \langle tl:1, tp:F, th:T, st \rangle \\ \langle tl:1, tp:F, th:F, sp \rangle \\ \langle tl:1, tp:F, th:F, pg \rangle \\ \langle tl:1, tp:F, th:F, pg \rangle \\ \langle tl:0, tp:F, th:T, oct \rangle \\ \langle tl:0, tp:F, th:T, oct \rangle \\ \langle tl:1, tp:T, th:T, st \rangle \\ \langle tl:1, tp:T, th:T, st \rangle \\ \langle tl:1, tp:F, th:T, ls \rangle \\ \langle tl:1, tp:F, th:T, st \rangle \\ \langle tl:1, tp:F, th:T, ls \rangle \\ \langle tl:1, tp:F, th:T, ls \rangle \\ \langle tl:1, tp:F, th:T, ls \rangle \\ \langle tl:1, tp:F, th:F, pg \rangle \\ \langle tl:1, tp:F, th:F, pg \rangle \\ \langle tl:1, tp:F, th:T, oct \rangle \\ \langle tl:1, tp:F, th:T, oct \rangle \\ \langle tl:0, tp:F, th:F, pg \rangle \\ \langle tl:0, tp:F, th:F, pg \rangle \\ \langle tl:0, tp:F, th:T, oct \rangle \\ \langle tl:0, tp:F, th:F, pg \rangle \\ \langle tl:0, tp:F, th:F, tp:F, tp:$?	21.65 0.59 1.15 1.33 4.88 2.04 1.95 0.84 1.37 1.13 4.92 1.98 0.68 97.85 39.82 11.62 341.43 158.71 132.34 74.51 34.18 82.49	74.85 12.62 12.48 15.01 14.00 17.36 11.63 14.54 14.71 12.91 13.73 17.14 15.01 47.67 57.33 64.64 42.19 37.96 86.47 58.20 277.23 181.04 91.41 31.70
8. last-ev-even	evDrift Drift	\(\lambda(t)\). \(\lambda(p)\). \(\text{F}\). \(\text{t}\). \(\text{t}\)	?	21.65 0.59 1.15 1.33 4.88 2.04 1.37 1.13 4.92 1.98 0.68 46.35 86.08 97.85 39.82 11.62 341.43 158.71 132.34 74.51 34.18	74.85 12.62 12.48 15.01 14.00 17.36 11.63 14.54 14.71 12.91 13.73 17.14 15.01 47.67 57.33 64.64 42.19 37.96 86.47 58.20 277.23 181.04 91.41 31.70

	evDrift evDrift	$\langle tl:0, tp:F, th:T, oct \rangle$ $\langle tl:0, tp:F, th:F, pq \rangle$?	0.56 2.33	16.95 11.98
	evDrift	$\langle tl:1, tp:F, th:T, st \rangle$?	2.32	18.64
		$\langle tl:1, tp:T, th:T, oct \rangle$?	5.17	23.90
	evDrift evDrift	$\langle tl:1, tp:F, th:F, pg \rangle$ $\langle tl:0, tp:F, th:T, ls \rangle$?	5.55 0.57	15.61 15.79
	evDrift		?	3.69	14.11
		$\langle tl:1, tp:F, th:T, oct \rangle$?	2.74	22.78
	evDrift	$\langle tl:0, tp:F, th:T, st \rangle$?	0.70	21.44
	evDrift evDrift	$\langle tl:1, tp:T, th:F, pg \rangle$ $\langle tl:1, tp:T, th:T, st \rangle$?	9.64 4.38	20.44 16.48
	evDrift	$\langle tl:1, tp:F, th:T, ls \rangle$?	1.92	15.20
9. lics18-amortized	D	/ il 4 in E il T l \	4.4	I 5 (0)	77.00
	Drift Drift	$\langle tl:1, tp:F, th:T, ls \rangle$ $\langle tl:1, tp:T, th:T, st \rangle$	4;4 4;4	5.63 6.10	76.86 83.79
	DRIFT	$\langle tl:1, tp:T, th:T, ls \rangle$	**	5.51	79.32
	Drift	$\langle tl:1, tp:F, th:T, st \rangle$	**	6.02	90.50
	DRIFT	$\langle tl:0, tp:F, th:T, st \rangle$	44	9.81	98.20
	Drift Drift	$\langle tl:0, tp:F, th:F, pg \rangle$ $\langle tl:0, tp:F, th:T, oct \rangle$	4;4 4;4	73.37 82.16	58.47 308.48
	DRIFT	$\langle tl:1, tp:F, th:T, oct \rangle$	44	39.59	291.05
	Drift	$\langle tl:1, tp:T, th:T, oct \rangle$	* * *	37.39	274.43
	DRIFT	$\langle tl:1, tp:F, th:F, pg \rangle$	**	30.12	55.58
	Drift Drift	$\langle tl:1, tp:T, th:F, pg \rangle$ $\langle tl:0, tp:F, th:T, ls \rangle$	*	30.89 9.28	51.70 93.19
	evDrift		シ	49.56	45.41
	ev Drift	$\langle tl:0, tp:F, th:T, ls \rangle$?	14.92	55.87
	evDrift		? ? •	281.67	54.61
	evDRIFT evDRIFT	$\langle tl:1, tp:T, th:T, oct \rangle$ $\langle tl:1, tp:F, th:T, st \rangle$	رُ	91.85 50.23	162.00 54.74
	evDrift		?	50.72	30.35
		$\langle tl:0, tp:F, th:T, oct \rangle$?	29.27	103.17
	evDrift	$\langle tl:1, tp:F, th:T, ls \rangle$	7	41.63	44.56
	evDrift evDrift	$\langle tl:1, tp:T, th:T, st \rangle$ $\langle tl:1, tp:T, th:F, pg \rangle$?	58.59 309.36	54.73 57.73
	evDrift	$\langle tl:1, tp:F, th:T, oct \rangle$?	82.07	154.26
	ev Drift	$\langle tl:0,tp:F,th:T,st\rangle$?	17.84	81.72
10. lics18-hoshrink	Drift	$\langle tl:1, tp:T, th:F, pq \rangle$	T	900.25	127.38
	DRIFT	$\langle tl:1, tp:F, th:F, pg \rangle$	Ť	900.27	127.12
	Drift	$\langle tl:0, tp:F, th:T, ls \rangle$?	28.52	68.10
	DRIFT	$\langle tl:1, tp:T, th:T, oct \rangle$?	376.31	647.40
	Drift Drift	$\langle tl:0, tp:F, th:T, st \rangle$ $\langle tl:0, tp:F, th:F, pg \rangle$?	32.53 656.41	71.09 77.61
	DRIFT	$\langle tl:1, tp:F, th:T, oct \rangle$?	378.08	292.16
	Drift	$\langle tl:0, tp:F, th:T, oct \rangle$?	101.21	309.49
	DRIFT	$\langle tl:1, tp:F, th:T, st \rangle$?	164.20	138.56
	Drift Drift	$\langle tl:1, tp:T, th:T, ls \rangle$ $\langle tl:1, tp:T, th:T, st \rangle$?	157.87 175.37	131.98 139.32
	DRIFT	$\langle tl:1, tp:F, th:T, ls \rangle$?	150.07	131.40
	evDrift	$\langle tl:1, tp:T, th:F, pg \rangle$? ? ?	24.55	22.06
	evDrift evDrift	$\langle tl:0, tp:F, th:T, st \rangle$ $\langle tl:1, tp:F, th:T, oct \rangle$?	0.65 1.42	12.35 15.34
	evDrift	$\langle tl:1, tp:F, th:T, ls \rangle$?	3.36	14.10
	ev Drift	$\langle tl:1, tp:T, th:T, st \rangle$?	4.06	15.68
	evDrift		?	5.13	13.55
	evDrift evDrift	$\langle tl:0, tp:F, th:T, oct \rangle$ $\langle tl:1, tp:F, th:F, pg \rangle$?	0.61 24.46	14.32 22.05
		$\langle tl:1, tp:T, th:T, oct \rangle$?	1.45	15.61
	ev Drift	$\langle tl:1, tp:F, th:T, st \rangle$?	3.96	15.28
	evDrift evDrift		?	3.43 0.58	14.23 10.90
11. lics18-web	CADKILI	ip.1, im.1, is/	•	0.50	10.70
	Drift	$\langle tl:1, tp:T, th:T, oct \rangle$	T		1000.00
	DRIFT	$\langle tl:1, tp:F, th:T, oct \rangle$	T	930.99	207.94
	Drift Drift	$\langle tl:0, tp:F, th:T, oct \rangle$ $\langle tl:0, tp:F, th:F, pq \rangle$	T T	930.95 900.25	692.67 109.28
	DRIFT	$\langle tl:0,tp:F,th:T,st\rangle$	M	142.62	1000.00
	Drive	$\langle tl:0,tp:F,th:T,ls\rangle$	M	220.48	1000.00
	DRIFT		ar.		150.00
	Drift	$\langle tl:1, tp:T, th:F, pg \rangle$	T	900.25	159.30 158.43
		$\langle tl:1, tp:T, th:F, pg \rangle$ $\langle tl:1, tp:F, th:F, pg \rangle$	T T T		159.30 158.43 511.11
	Drift Drift	$\langle tl:1, tp:T, th:F, pg \rangle$	T	900.25 900.25	158.43 511.11

Drift				
DRIFI	$\langle tl:1, tp:F, th:T, st \rangle$	T	900.26	672.79
Drift	$\langle tl:1, tp:T, th:T, ls \rangle$	Ţ	900.27	944.81
ev Drift	\ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \	~	124.58	73.92
evDrift	$\langle tl:1, tp:F, th:T, ls \rangle$	~	108.37	68.19
evDrift	$\langle tl:0, tp:F, th:T, st \rangle$	~	38.88	57.98
ev Drift		1	266.10	191.73
evDrift		?	223.60	49.93
evDrift	$\langle tl:1, tp:F, th:T, st \rangle$	~	122.76	74.98
evDrift	$\langle tl:1, tp:T, th:T, oct \rangle$	~	258.78	190.05
ev Drift		?	212.98	50.45
_		V		
evDrift			35.46	51.51
evDrift		~	111.36	66.06
evDrift	$\langle tl:0,tp:F,th:T,oct \rangle$	~	88.81	115.75
ev Drift	$\langle tl:0,tp:F,th:F,pq\rangle$?	35.27	22.17
12. market	(****, *******, *******, ******			
DRIFT	1/+1-1 +p.T +h.T oct\1	T	000.25	1000.00
	$\langle tl:1, tp:T, th:T, oct \rangle$			
Drift	$\langle tl:0, tp:F, th:T, st \rangle$	M		1000.00
Drift	$\langle tl:0, tp:F, th:T, oct \rangle$	T	930.87	679.81
Drift	$\langle tl:1, tp:F, th:T, oct \rangle$	T	930.96	149.89
Drift	$\langle tl:0, tp:F, th:F, pq \rangle$	$\hat{\mathbf{T}}$	900.24	125.42
_	(11.0, tp.1, th.1, pg/			
DRIFT	$\langle tl:0, tp:F, th:T, ls \rangle$	M		1000.00
Drift	$\langle tl:1, tp:F, th:F, pg \rangle$	T	900.25	195.15
Drift	$\langle tl:1, tp:T, th:F, pq \rangle$	T	900.24	135.80
DRIFT	$\langle tl:1, tp:T, th:T, st \rangle$	Ť	930.93	228.10
Drift	$\langle tl:1, tp:F, th:T, ls \rangle$	T	930.98	187.17
Drift	$\langle tl:1, tp:F, th:T, st \rangle$	T	900.25	291.75
Drift	$\langle tl:1, tp:T, th:T, ls \rangle$	T	900.25	280.31
ev Drift		?	50.06	56.15
evDrift		?	69.70	61.32
		•		
ev Drift		?	73.98	123.82
evDrift	$\langle tl:0, tp:F, th:T, st \rangle$? ? ?	36.98	86.41
evDrift	$\langle tl:1, tp:T, th:F, pq \rangle$?	117.76	41.66
ev Drift		?	75.53	131.35
_		2		
evDrift		٠	114.07	41.05
ev Drift		?	59.63	65.43
evDrift	$\{tl:1,tp:T,th:T,ls\}$?	58.36	53.19
ev Drift	$\langle tl:0,tp:F,th:T,ls\rangle$?	30.42	69.75
evDrift	10. 11. 11.	?	40.01	96.99
_		?		
evDrift	$\langle tl:0,tp:F,th:F,pg\rangle$	•	81.68	30.53
13. max-min		_		
Drift				i
DRIFT	$\langle tl:1, tp:T, th:T, oct \rangle$	T	900.25	954.77
DRIFT		T	900.25 931.00	
Drift	$\langle tl:0, tp:F, th:T, oct \rangle$	T	931.00	503.20
Drift Drift	$\langle tl:0, tp:F, th:T, oct \rangle$ $\langle tl:1, tp:F, th:T, oct \rangle$	T T	931.00 930.96	503.20 77.75
Drift Drift Drift	$ \begin{array}{l} \langle tl : 0, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \end{array} $	T T T	931.00 930.96 900.24	503.20 77.75 107.82
Drift Drift	$ \begin{array}{l} \langle tl : 0, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \end{array} $	T T T	931.00 930.96 900.24 900.27	503.20 77.75 107.82 787.07
Drift Drift Drift	$ \begin{array}{l} \langle tl : 0, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \end{array} $	T T T	931.00 930.96 900.24	503.20 77.75 107.82 787.07
Drift Drift Drift Drift Drift	$ \begin{array}{l} \langle tl:0,tp:F,th:T,oct\rangle \\ \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:F,pg\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:0,tp:F,th:T,ls\rangle \end{array} $	T T T	931.00 930.96 900.24 900.27	503.20 77.75 107.82 787.07 541.23
Drift Drift Drift Drift Drift Drift Drift	$ \begin{array}{l} \langle tl : 0, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 0, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \end{array} $	T T T T T	931.00 930.96 900.24 900.27 930.93 900.25	503.20 77.75 107.82 787.07 541.23 168.78
DRIFT DRIFT DRIFT DRIFT DRIFT DRIFT DRIFT DRIFT DRIFT	$ \begin{array}{l} \langle tl : 0, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 0, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : F, pg \rangle \\ \end{array} $	T T T T T T	931.00 930.96 900.24 900.27 930.93 900.25 900.25	503.20 77.75 107.82 787.07 541.23 168.78 147.80
DRIFT	$ \begin{array}{l} \langle tl.0, fp.F, th.T, oct \rangle \\ \langle tl.1, tp.F, th.T, oct \rangle \\ \langle tl.0, tp.F, th.F, pg \rangle \\ \langle tl.0, tp.F, th.F, st \rangle \\ \langle tl.0, tp.F, th.T, ls \rangle \\ \langle tl.1, tp.F, th.F, pg \rangle \\ \langle tl.1, tp.T, th.F, pg \rangle \\ \langle tl.1, tp.T, th.F, st \rangle \\ \langle tl.1, tp.T, th.T, st \rangle \\ \end{array} $	T T T T T T	931.00 930.96 900.24 900.27 930.93 900.25 930.98	503.20 77.75 107.82 787.07 541.23 168.78 147.80 238.50
Drift Drift Drift Drift Drift Drift Drift Drift Drift	$ \begin{array}{l} \langle tl : 0, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 0, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \end{array} $	T T T T T T T	931.00 930.96 900.24 900.27 930.93 900.25 900.25 930.98 930.99	503.20 77.75 107.82 787.07 541.23 168.78 147.80 238.50 180.47
DRIFT	$ \begin{array}{l} \langle tl : 0, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 0, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \end{array} $	T T T T T T	931.00 930.96 900.24 900.27 930.93 900.25 930.98	503.20 77.75 107.82 787.07 541.23 168.78 147.80 238.50 180.47
Drift Drift Drift Drift Drift Drift Drift Drift Drift	$ \begin{array}{l} \langle tl : 0, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 0, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \end{array} $	T T T T T T T	931.00 930.96 900.24 900.27 930.93 900.25 900.25 930.98 930.99	503.20 77.75 107.82 787.07 541.23 168.78 147.80 238.50 180.47 328.82
DRIFT	$ \begin{array}{l} \langle tl : 0, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 0, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \end{array} $	T T T T T T T T	931.00 930.96 900.24 900.27 930.93 900.25 930.98 930.99 900.25 900.25	503.20 77.75 107.82 787.07 541.23 168.78 147.80 238.50 180.47 328.82 320.47
Drift	$ \begin{array}{l} \langle tl.0, tp.F, th.T, oct \rangle \\ \langle tl.1, tp.F, th.T, oct \rangle \\ \langle tl.0, tp.F, th.F, pg \rangle \\ \langle tl.0, tp.F, th.F, st \rangle \\ \langle tl.0, tp.F, th.T, ls \rangle \\ \langle tl.1, tp.F, th.F, pg \rangle \\ \langle tl.1, tp.T, th.F, pg \rangle \\ \langle tl.1, tp.T, th.F, st \rangle \\ \langle tl.1, tp.F, th.T, ls \rangle \\ \langle tl.1, tp.F, th.T, ls \rangle \\ \langle tl.1, tp.F, th.T, ls \rangle \\ \langle tl.1, tp.T, th.T, st \rangle \\ \langle tl.1, tp.T, th.T, st \rangle \\ \langle tl.1, tp.T, th.T, ls \rangle \\ \langle tl.1, tp.T, th.T, st \rangle \\ \end{array} $	T T T T T T T T	931.00 930.96 900.24 900.27 930.93 900.25 930.98 930.99 900.25 900.25 124.00	503.20 77.75 107.82 787.07 541.23 168.78 147.80 238.50 180.47 328.82 320.47 91.60
Drift EvDrift evDrift	$ \begin{array}{l} \langle tl : 0, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 0, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \end{array} $	T T T T T T T T T	931.00 930.96 900.24 900.27 930.93 900.25 930.98 930.99 900.25 900.25 124.00 14.27	503.20 77.75 107.82 787.07 541.23 168.78 147.80 238.50 180.47 328.82 320.47 91.60 38.24
Drift EvDrift evDrift evDrift	$ \begin{array}{l} \langle tl : 0, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 0, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \end{array} $	T T T T T T T T T T ? ?	931.00 930.96 900.24 900.27 930.93 900.25 930.98 930.99 900.25 124.00 14.27 10.06	503.20 77.75 107.82 787.07 541.23 168.78 147.80 238.50 180.47 91.60 38.24 67.75
Drift EvDrift evDrift	$ \begin{array}{l} \langle tl : 0, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : F, st \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle $	T T T T T T T T T T T ? ? ? ?	931.00 930.96 900.24 900.27 930.93 900.25 930.98 930.99 900.25 900.25 124.00 14.27	503.20 77.75 107.82 787.07 541.23 168.78 147.80 238.50 180.47 91.60 38.24 67.75
Drift EvDrift evDrift evDrift evDrift	$ \begin{array}{l} \langle tl : 0, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : F, st \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle $	T T T T T T T T T T T ? ?	931.00 930.96 900.24 900.27 930.93 900.25 900.25 930.98 930.99 900.25 124.00 14.27 10.06 20.66	503.20 77.75 107.82 787.07 541.23 168.78 147.80 238.50 180.47 328.82 320.47 91.60 38.24 67.75 68.19
Drift EvDrift evDrift evDrift evDrift evDrift	$ \begin{array}{l} \langle tl.0, tp.F, th.T, oct \rangle \\ \langle tl.1, tp.F, th.T, oct \rangle \\ \langle tl.0, tp.F, th.F, pg \rangle \\ \langle tl.0, tp.F, th.F, pg \rangle \\ \langle tl.0, tp.F, th.T, st \rangle \\ \langle tl.1, tp.F, th.F, pg \rangle \\ \langle tl.1, tp.T, th.F, pg \rangle \\ \langle tl.1, tp.T, th.F, pg \rangle \\ \langle tl.1, tp.T, th.T, st \rangle \\ \langle tl.1, tp.F, th.T, st \rangle \\ \langle tl.1, tp.F, th.T, ls \rangle \\ \langle tl.1, tp.F, th.T, t, st \rangle \\ \langle tl.1, tp.F, th.T, t, st \rangle \\ \langle tl.1, tp.F, th.T, st \rangle \\ \langle tl.1, tp.T, th.T, st \rangle \\ \langle tl.$	T T T T T T T T T T T T ? ? ? ? ?	931.00 930.96 900.24 900.27 930.93 900.25 930.98 930.99 900.25 124.00 14.27 10.06 615.45	503.20 77.75 107.82 787.07 541.23 168.78 147.80 238.50 180.47 328.82 320.47 91.60 38.24 67.75 68.19 95.70
DRIFT EVDRIFT	$ \begin{array}{l} \langle tl : 0, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \end{array}$	T T T T T T T T T T T T ? ? ? ? ? ? ? ?	931.00 930.96 900.24 900.27 930.93 900.25 900.25 900.25 124.00 14.27 10.06 20.66 615.45 19.36	503.20 77.75 107.82 787.07 541.23 168.78 147.80 238.50 180.47 328.82 320.47 91.60 38.24 67.75 68.19 95.70 55.51
DRIFT EVDRIFT	$ \begin{array}{l} \langle tl : 0, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 0, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, pg \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : $	T T T T T T T T T T T T T ? ? ? ? ? ? ?	931.00 930.96 900.24 900.27 930.93 900.25 930.98 930.99 900.25 124.00 14.27 10.06 615.45 19.36 243.23	503.20 77.75 107.82 787.07 541.23 168.78 147.80 238.50 180.47 328.82 320.47 91.60 38.24 67.75 68.19 95.70 55.51 512.68
DRIFT EVDRIFT	$ \begin{array}{l} \langle tl : 0, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 0, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : T, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \end{array}$	T T T T T T T T T T T T T T T T T T T	931.00 930.96 900.24 900.27 930.93 900.25 930.98 930.99 900.25 124.00 14.27 10.06 20.66 615.45 19.36 243.23 92.99	503.20 77.75 107.82 787.07 541.23 168.78 147.80 238.50 180.47 328.82 320.47 91.60 38.24 67.75 68.19 95.70 55.51 512.68 37.17
DRIFT EVDRIFT	$ \begin{array}{l} \langle tl : 0, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 0, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : T, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : T, sp \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \end{array} $	T T T T T T T T T T T T T T T T T T T	931.00 930.96 900.24 900.27 930.93 900.25 930.98 930.99 900.25 124.00 14.27 10.06 615.45 19.36 243.23	503.20 77.75 107.82 787.07 541.23 168.78 147.80 238.50 180.47 328.82 320.47 91.60 38.24 67.75 68.19 95.70 55.51 512.68 37.17
DRIFT EVDRIFT	$ \langle tl : 0, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : F, st \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 0, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : T, ls \rangle $	T T T T T T T T T T T T T T T T T T T	931.00 930.96 900.24 900.27 930.93 900.25 930.98 930.99 900.25 124.00 14.27 10.06 20.66 615.45 19.36 243.23 92.99	503.20 77.75 107.82 787.07 541.23 168.78 147.80 238.50 180.47 328.82 320.47 91.60 38.24 67.75 68.19 95.70 55.51 512.68 37.17 45.86
DRIFT EVDRIFT	$ \langle tl : 0, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : F, st \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 0, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle $	T T T T T T T T T T T T T T T T T T T	931.00 930.96 900.24 900.27 930.93 900.25 930.98 930.99 900.25 124.00 14.27 10.06 615.45 19.36 243.23 92.99 7.58 89.98	503.20 77.75 107.82 787.07 541.23 168.78 147.80 238.50 180.47 328.82 320.47 91.60 38.24 67.75 68.19 95.70 55.51 512.68 37.17 45.86 80.33
DRIFT evDRIFT	$ \begin{array}{l} \langle tl : 0, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 0, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : $	T T T T T T T T T T T T T T T T T T T	931.00 930.96 900.24 900.27 930.93 900.25 930.98 930.99 900.25 124.00 14.27 10.06 20.66 615.45 19.36 243.23 92.99 7.85 89.98 14.05	503.20 77.75 107.82 787.07 541.23 168.78 147.80 238.50 180.47 328.82 320.47 91.60 38.24 67.75 68.19 95.70 55.51 512.68 37.17 48.83 49.70
DRIFT EVDRIFT	$ \begin{array}{l} \langle tl : 0, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 0, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : $	T T T T T T T T T T T T T T T T T T T	931.00 930.96 900.24 900.27 930.93 900.25 930.98 930.99 900.25 124.00 14.27 10.06 615.45 19.36 243.23 92.99 7.58 89.98	503.20 77.75 107.82 787.07 541.23 168.78 147.80 238.50 180.47 328.82 320.47 91.60 38.24 67.75 68.19 95.70 55.51 512.68 37.17 48.83 49.70
DRIFT EVDRIFT	$ \langle tl : 0, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 0, tp : F, th : T, ls \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle $	T T T T T T T T T T T T T T T T T T T	931.00 930.96 900.24 900.25 900.25 930.98 930.99 900.25 124.00 14.27 10.06 615.45 19.36 243.23 92.99 7.58 89.98 14.05 61.27	503.20 77.75 107.82 787.07 541.23 168.78 147.80 238.50 180.47 328.82 320.47 91.60 38.24 67.75 68.19 95.70 55.51 512.68 37.17 45.86 80.33 49.70 28.16
DRIFT EVDRIFT	$ \langle tl : 0, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : F, st \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 0, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : T, th : F, pg \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, pg \rangle \\ \\ \langle tl : 1, tp : F, th : T, pg \rangle \\ \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, pg \rangle \\ \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\$	T T T T T T T T T T T T T T T T T T T	931.00 930.96 900.24 900.27 930.93 900.25 930.98 930.99 900.25 124.00 14.27 10.06 615.45 19.36 243.23 92.99 7.58 89.98 14.05 61.27	503.20 77.75 107.82 787.07 541.23 168.78 147.80 238.50 180.47 328.82 320.47 91.60 38.24 67.75 68.19 95.70 55.51 512.68 37.17 45.86 80.33 49.70 28.16
DRIFT EVDRIFT for the	$ \langle tl:0, tp:F, th:T, oct \rangle \\ \langle tl:1, tp:F, th:T, oct \rangle \\ \langle tl:1, tp:F, th:T, cot \rangle \\ \langle tl:0, tp:F, th:F, pg \rangle \\ \langle tl:0, tp:F, th:T, st \rangle \\ \langle tl:0, tp:F, th:T, ls \rangle \\ \langle tl:1, tp:F, th:F, pg \rangle \\ \langle tl:1, tp:T, th:F, pg \rangle \\ \langle tl:1, tp:T, th:T, st \rangle \\ \langle tl:1, tp:F, th:T, st \rangle \\ \langle tl:1, tp:F, th:T, st \rangle \\ \langle tl:1, tp:F, th:T, st \rangle \\ \langle tl:1, tp:T, th:T, st \rangle \\ \langle tl:1, tp:T, th:T, st \rangle \\ \langle tl:1, tp:F, th:T, ls \rangle \\ \langle tl:0, tp:F, th:T, ls \rangle \\ \langle tl:0, tp:F, th:T, st \rangle \\ \langle tl:1, tp:T, th:T, st \rangle \\ \langle tl:1, tp:F, th:T, st \rangle \\ \langle tl:1, tp:T, th:T, ls \rangle \\ \langle tl:1, tp:T, th:T, ls \rangle \\ \langle tl:1, tp:T, th:T, ls \rangle \\ \langle tl:1, tp:T, th:T, tl,T, th:T, th:T$	T T T T T T T T T T T T T T T T T T T	931.00 930.96 900.24 900.27 930.93 900.25 930.98 930.99 900.25 124.00 14.27 10.06 20.66 615.45 19.36 243.23 92.99 7.58 89.98 14.05 61.27	503.20 77.75 107.82 787.07 541.23 168.78 147.80 238.50 180.47 91.60 38.24 67.75 68.19 95.70 55.51 512.68 37.17 45.86 80.33 49.70 28.16
DRIFT EVDRIFT	$ \langle tl : 0, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : F, st \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 0, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : T, th : F, pg \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, pg \rangle \\ \\ \langle tl : 1, tp : F, th : T, pg \rangle \\ \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, pg \rangle \\ \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\$	T T T T T T T T T T T T T T T T T T T	931.00 930.96 900.24 900.27 930.93 900.25 930.98 930.99 900.25 124.00 14.27 10.06 615.45 19.36 243.23 92.99 7.58 89.98 14.05 61.27	503.20 77.75 107.82 787.07 541.23 168.78 147.80 238.50 180.47 91.60 38.24 67.75 68.19 95.70 55.51 512.68 37.17 45.86 80.33 49.70 28.16
DRIFT EVDRIFT for DRIFT evDRIFT evDRIFT evDRIFT for DRIFT evDRIFT for DRIFT for DRIFT evDRIFT for DRIFT for DRIFT DRIFT DRIFT DRIFT	$ \langle tl : 0, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : F, st \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 0, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle $	T T T T T T T T T T T T T T T T T T T	931.00 930.96 900.24 900.27 930.93 900.25 930.98 930.99 900.25 124.00 14.27 10.06 20.66 615.45 19.36 243.23 92.99 7.58 89.98 14.05 61.27	503.20 77.75 107.82 787.07 541.23 168.78 147.80 238.50 180.47 91.60 38.24 67.75 68.19 95.70 55.51 512.68 37.17 45.86 80.33 49.70 28.16
DRIFT EVDRIFT DRIFT DRIFT DRIFT DRIFT DRIFT DRIFT DRIFT	$ \langle tl:0, tp:F, th:T, oct \rangle \\ \langle tl:1, tp:F, th:T, oct \rangle \\ \langle tl:0, tp:F, th:F, pg \rangle \\ \langle tl:0, tp:F, th:F, st \rangle \\ \langle tl:0, tp:F, th:T, st \rangle \\ \langle tl:0, tp:F, th:T, ls \rangle \\ \langle tl:1, tp:F, th:F, pg \rangle \\ \langle tl:1, tp:T, th:F, pg \rangle \\ \langle tl:1, tp:T, th:T, st \rangle \\ \langle tl:1, tp:F, th:T, ls \rangle \\ \langle tl:1, tp:F, th:T, st \rangle \\ \langle tl:1, tp:F, th:T, st \rangle \\ \langle tl:1, tp:F, th:T, st \rangle \\ \langle tl:1, tp:T, th:T, ts \rangle \\ \langle tl:T, tp:T, tt:T, tt:T, ts \rangle \\ \langle tl:T, tp$	T T T T T T T T T T T T T T T T T T T	931.00 930.96 900.24 900.27 930.93 900.25 930.98 930.99 900.25 124.00 14.27 10.06 620.66 615.45 19.36 243.23 92.99 7.58 89.98 14.05 61.27	503.20 77.75 107.82 787.07 541.23 168.78 147.80 238.50 180.47 328.82 320.47 91.60 38.24 67.75 68.19 95.70 55.51 512.68 37.17 45.86 80.33 49.70 28.16
DRIFT EVDRIFT DRIFT	\langle tl:0, \(\psi p: F, \th: T, \to ct \rangle \) \(tl:1, \text{tp: F, th: T, oct} \rangle \) \(tl:0, \text{tp: F, th: F, pg} \rangle \) \(tl:0, \text{tp: F, th: T, st} \rangle \) \(tl:0, \text{tp: F, th: T, ls} \rangle \) \(tl:1, \text{tp: F, th: F, pg} \rangle \) \(tl:1, \text{tp: T, th: T, st} \rangle \) \(tl:1, \text{tp: T, th: T, st} \rangle \) \(tl:1, \text{tp: F, th: T, st} \rangle \) \(tl:1, \text{tp: T, th: T, st} \rangle \) \(tl:1, \text{tp: T, th: T, st} \rangle \) \(tl:1, \text{tp: T, th: T, st} \rangle \) \(tl:1, \text{tp: F, th: T, oct} \rangle \) \(tl:1, \text{tp: F, th: T, oct} \rangle \) \(tl:1, \text{tp: F, th: T, ls} \rangle \) \(tl:1, \text{tp: F, th: T, ls} \rangle \) \(tl:1, \text{tp: F, th: T, ls} \rangle \) \(tl:1, \text{tp: F, th: T, ls} \rangle \) \(tl:1, \text{tp: F, th: T, ls} \rangle \) \(tl:1, \text{tp: F, th: T, ls} \rangle \) \(tl:1, \text{tp: T, th: T, ls} \rangle \) \(tl:1,	T T T T T T T T T T T T T T T T T T T	931.00 930.96 900.24 900.25 900.25 900.25 900.25 124.00 14.27 10.06 20.66 615.45 19.36 243.23 92.99 7.58 89.98 14.05 61.27	503.20 77.75 107.82 787.07 541.23 168.78 147.80 238.50 180.47 328.82 320.47 91.60 38.24 67.75 68.19 95.70 55.51 512.68 80.33 49.70 28.16
DRIFT EVDRIFT DRIFT	\(\langle \text{tl:0}, \(tp:F, \text{th:T}, \text{oct}\) \(\langle \text{tl:1}, \text{tp:F}, \text{th:T}, \text{oct}\) \(\langle \text{tl:0}, \text{tp:F}, \text{th:T}, \text{st}\) \(\langle \text{tl:0}, \text{tp:F}, \text{th:T}, \text{st}\) \(\langle \text{tl:1}, \text{tp:F}, \text{th:T}, \text{ts}\) \(\langle \text{tl:1}, \text{tp:T}, \text{th:T}, \text{st}\) \(\langle \text{tl:1}, \text{tp:T}, \text{th:T}, \text{st}\) \(\langle \text{tl:1}, \text{tp:F}, \text{th:T}, \text{st}\) \(\langle \text{tl:1}, \text{tp:F}, \text{th:T}, \text{st}\) \(\langle \text{tl:1}, \text{tp:T}, \text{th:T}, \text{st}\) \(\langle \text{tl:1}, \text{tp:F}, \text{th:T}, \text{st}\) \(\langle \text{tl:1}, \text{tp:T},	T T T T T T T T T T T T T T T T T T T	931.00 930.96 900.24 900.27 930.93 900.25 900.25 124.00 14.27 10.06 20.66 615.45 19.36 243.23 92.99 7.58 89.98 14.05 61.27	503.20 77.75 107.82 787.07 541.23 168.78 147.80 238.50 180.47 328.82 320.47 91.60 38.24 67.75 68.19 95.70 55.51 512.68 37.17 45.86 80.33 49.70 28.16
DRIFT EVDRIFT TORIFT EVDRIFT DRIFT	$ \begin{array}{l} \langle tl.0, tp:F, th:T, oct \rangle \\ \langle tl.1, tp:F, th:T, oct \rangle \\ \langle tl.1, tp:F, th:T, oct \rangle \\ \langle tl.0, tp:F, th:F, pg \rangle \\ \langle tl.0, tp:F, th:F, pg \rangle \\ \langle tl.0, tp:F, th:T, ls \rangle \\ \langle tl.1, tp:F, th:F, pg \rangle \\ \langle tl.1, tp:T, th:F, pg \rangle \\ \langle tl.1, tp:T, th:T, st \rangle \\ \langle tl.1, tp:T, th:T, ls \rangle \\ \langle tl.1, tp:F, th:T, st \rangle \\ \langle tl.1, tp:F, th:T, ls \rangle \\ \langle tl.1, tp:F, th:T, st \rangle \\ \langle tl.1, tp:F, th:T, ls \rangle \\ \langle tl.1, tp:F, th:T, th:F, pg \rangle \\ \langle tl.1, tp:F, th:T, th:F, th:T, ts \rangle \\ \langle tl.1, tp:F, th:T, th:F, th:T, ts \rangle \\ \langle tl.1, tp:F, th:T, th:F, th:T, ts \rangle \\ \langle tl.1, tp:F, th:T, th:F, th:T, ts \rangle \\ \langle tl.1, tp:F, th:T, th:F, th:T, ts \rangle \\ \langle tl.1, tp:F, th:T, th:F, th:T, ts \rangle \\ \langle tl.1, tp:F, th:T, th:F, th:T, ts \rangle \\ \langle tl.1, tp:F,$	T T T T T T T T T T T T T T T T T T T	931.00 930.96 900.24 900.27 930.93 900.25 930.98 930.99 900.25 124.00 14.27 10.06 615.45 19.36 243.23 92.99 7.58 89.98 14.05 61.27 18.78 21.45 24.32 16.29 148.35 136.74 13.31	503.20 77.75 107.82 787.07 541.23 168.78 147.80 238.50 180.47 91.60 38.24 67.75 68.19 95.70 55.51 512.68 80.33 49.70 28.16 35.04 36.11 40.22 30.64 42.90 37.78 69.54
DRIFT EVDRIFT DRIFT	\(\langle \text{tl:0}, \(tp:F, \text{th:T}, \text{oct}\) \(\langle \text{tl:1}, \text{tp:F}, \text{th:T}, \text{oct}\) \(\langle \text{tl:0}, \text{tp:F}, \text{th:T}, \text{st}\) \(\langle \text{tl:0}, \text{tp:F}, \text{th:T}, \text{st}\) \(\langle \text{tl:1}, \text{tp:F}, \text{th:T}, \text{ts}\) \(\langle \text{tl:1}, \text{tp:T}, \text{th:T}, \text{st}\) \(\langle \text{tl:1}, \text{tp:T}, \text{th:T}, \text{st}\) \(\langle \text{tl:1}, \text{tp:F}, \text{th:T}, \text{st}\) \(\langle \text{tl:1}, \text{tp:F}, \text{th:T}, \text{st}\) \(\langle \text{tl:1}, \text{tp:T}, \text{th:T}, \text{st}\) \(\langle \text{tl:1}, \text{tp:F}, \text{th:T}, \text{st}\) \(\langle \text{tl:1}, \text{tp:T},	T T T T T T T T T T T T T T T T T T T	931.00 930.96 900.24 900.27 930.93 900.25 900.25 124.00 14.27 10.06 20.66 615.45 19.36 243.23 92.99 7.58 89.98 14.05 61.27	503.20 77.75 107.82 787.07 541.23 168.78 147.80 238.50 180.47 91.60 38.24 67.75 68.19 95.70 55.51 512.68 80.33 49.70 28.16 35.04 36.11 40.22 30.64 42.90 37.78 69.54

	Drift	$\langle tl:0, tp:F, th:F, pq \rangle$?	47.34	25.86
	Drift	$\langle tl:1, tp:F, th:T, oct \rangle$	~	31.36	48.75
	Drift	$\langle tl:0, tp:F, th:T, oct \rangle$?	26.80	116.63
	Drift	$\langle tl:0,tp:F,th:T,st\rangle$?	16.86	76.88
	evDrift	$\langle tl:0, tp:F, th:F, pq \rangle$?	2.45	12.70
			•		
	<pre>evDrift</pre>	$\langle tl:0, tp:F, th:T, oct \rangle$?	0.60	17.41
	<pre>evDrift</pre>	$\langle tl:1, tp:F, th:T, st \rangle$	~	1.21	17.51
	evDrift	$\langle tl:1, tp:F, th:F, pq \rangle$	2	4.29	14.54
	evDrift	$\langle tl:1, tp:T, th:T, oct \rangle$??? ? ?	1.94	21.50
	ev Drift	$\langle tl:0, tp:F, th:T, ls \rangle$?	0.53	16.25
	evDrift	$\langle tl:1, tp:T, th:T, ls \rangle$	•	1.10	13.79
	evDrift	$\langle tl:1, tp:T, th:F, pg \rangle$?	4.48	14.89
	ev Drift	$\langle tl:0,tp:F,th:T,st\rangle$?	0.62	19.00
			?		
	evDrift			1.85	21.00
	ev Drift	$\langle tl:1, tp:T, th:T, st \rangle$	~	1.27	16.41
	evDrift	$\langle tl:1, tp:F, th:T, ls \rangle$	~	1.06	14.24
15. order-irrel	•••	(22.1,27.1,222.1,227		1.00	1 1.5 1
13. order - Irrel	ъ				005.54
	Drift	$\langle tl:1, tp:T, th:T, st \rangle$?	348.46	205.56
	Drift	$\langle tl:1, tp:F, th:T, ls \rangle$?	76.53	144.92
			?		
	Drift	$\langle tl:1, tp:F, th:T, st \rangle$		163.89	278.11
	Drift	$\langle tl:1, tp:T, th:T, ls \rangle$?	167.90	134.18
	Drift	$\langle tl:1, tp:T, th:T, oct \rangle$?	98.41	192.64
	_		2		
I	Drift	$\langle tl:0, tp:F, th:F, pg \rangle$		108.48	34.00
I	Drift	$\langle tl:0, tp:F, th:T, oct \rangle$?	38.46	173.21
I	Drift	$\langle tl:1, tp:F, th:T, oct \rangle$? ? ?	38.89	120.31
			•		
I	Drift	$\langle tl:0,tp:F,th:T,st\rangle$?	29.74	92.79
	Drift	$\langle tl:1, tp:F, th:F, pq \rangle$?	200.55	54.21
	Drift	$\langle tl:1, tp:T, th:F, pq \rangle$?	465.30	72.95
	_		•		
	Drift	$\langle tl:0, tp:F, th:T, ls \rangle$		21.31	79.46
	ev Drift	$\langle tl:1, tp:F, th:T, st \rangle$?	1.95	24.09
	evDrift		? ? ?	6.94	
			:		17.91
	ev Drift	$\langle tl:1, tp:T, th:T, oct \rangle$?	4.26	34.09
	ev Drift	$\langle tl:0,tp:F,th:T,ls\rangle$?	0.66	16.90
	evDrift		2		
		$\langle tl:1, tp:T, th:T, ls \rangle$? ? ? ?	3.58	21.48
	evDrift	$\langle tl:0, tp:F, th:F, pq \rangle$?	3.59	12.74
	ev Drift		?	0.81	22.88
			•		
	evDrift	$\langle tl:1, tp:T, th:T, st \rangle$	3	4.25	26.33
	evDrift	$\langle tl:1, tp:F, th:T, ls \rangle$?	1.65	20.18
	ev Drift	$\langle tl:1, tp:T, th:F, pg \rangle$	~	6.28	16.86
	ev Drift		?	1.85	27.07
	ev Drift	$\langle tl:0,tp:F,th:T,st\rangle$?	0.76	19.65
16. overview1					
10.010.110	Drift	$\langle tl:1, tp:F, th:T, st \rangle$	~	11.93	33.79
	Drift	$\langle tl:1, tp:T, th:T, ls \rangle$	~	12.18	30.27
	Drift	$\langle tl:1, tp:T, th:T, st \rangle$	~	13.76	34.19
	_		~		
	Drift	$\langle tl:1, tp:F, th:T, ls \rangle$		11.49	29.21
	Drift	$\langle tl:0, tp:F, th:T, ls \rangle$?	5.38	43.35
	Drift	$\langle tl:1, tp:F, th:F, pq \rangle$	~	49.36	31.94
I			~	49.96	33.60
	DRIFT	$\langle tl:1, tp:T, th:F, pg \rangle$	•		JJ.00
	Drift	$\langle tl:1, tp:T, th:T, oct \rangle$			00
			?	24.36	93.48
	Drift		?		
	DRIFT	$\langle tl:0,tp:F,th:T,st\rangle$?	6.49	60.65
	Drift	$\langle tl:0, tp:F, th:T, st \rangle$ $\langle tl:0, tp:F, th:T, oct \rangle$?	6.49 7.85	60.65 78.48
		$\langle tl:0,tp:F,th:T,st\rangle$? ? ?	6.49	60.65
	Drift Drift	$\langle tl:0, tp:F, th:T, st \rangle$ $\langle tl:0, tp:F, th:T, oct \rangle$ $\langle tl:1, tp:F, th:T, oct \rangle$? ? ? ?	6.49 7.85 22.06	60.65 78.48 86.84
	Drift Drift Drift	$\langle tl:0,tp:F,th:T,st\rangle$ $\langle tl:0,tp:F,th:T,oct\rangle$ $\langle tl:1,tp:F,th:T,oct\rangle$ $\langle tl:0,tp:F,th:F,pg\rangle$? ? ?	6.49 7.85 22.06 35.34	60.65 78.48 86.84 24.54
	Drift Drift Drift ev Drift	$ \begin{array}{c} \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:0,tp:F,th:T,oct\rangle \\ \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:1,tp:F,th:F,pg\rangle \\ \langle tl:0,tp:F,th:T,oct\rangle \\ \end{array} $? ? ? ?	6.49 7.85 22.06 35.34 0.61	60.65 78.48 86.84 24.54 21.66
	Drift Drift Drift	$\langle tl:0,tp:F,th:T,st\rangle$ $\langle tl:0,tp:F,th:T,oct\rangle$ $\langle tl:1,tp:F,th:T,oct\rangle$ $\langle tl:0,tp:F,th:F,pg\rangle$? ? ? ? ? >	6.49 7.85 22.06 35.34	60.65 78.48 86.84 24.54
	DRIFT DRIFT DRIFT evDRIFT evDRIFT	$\langle tl:0, tp:F, th:T, st \rangle$ $\langle tl:0, tp:F, th:T, oct \rangle$ $\langle tl:1, tp:F, th:T, oct \rangle$ $\langle tl:0, tp:F, th:F, pg \rangle$ $\langle tl:0, tp:F, th:T, oct \rangle$ $\langle tl:0, tp:F, th:F, pg \rangle$? ? ? ? ? >	6.49 7.85 22.06 35.34 0.61 1.10	60.65 78.48 86.84 24.54 21.66 12.21
	DRIFT DRIFT DRIFT evDRIFT evDRIFT evDRIFT	\(\lambda t l : 0, \text{tp:F, th:T, st}\) \(\lambda t l : 0, \text{tp:F, th:T, oct}\) \(\lambda t l : 0, \text{tp:F, th:T, oct}\) \(\lambda t l : 0, \text{tp:F, th:F, pg}\) \(\lambda t l : 0, \text{tp:F, th:F, pg}\) \(\lambda t l : 0, \text{tp:F, th:F, pg}\) \(\lambda t l : 1, \text{tp:T, th:T, oct}\)	????? > ?	6.49 7.85 22.06 35.34 0.61 1.10 2.10	60.65 78.48 86.84 24.54 21.66 12.21 27.89
	DRIFT DRIFT DRIFT evDRIFT evDRIFT evDRIFT evDRIFT	$\langle tl:0, tp:F, th:T, st \rangle$ $\langle tl:0, tp:F, th:T, oct \rangle$ $\langle tl:1, tp:F, th:T, oct \rangle$ $\langle tl:0, tp:F, th:F, pg \rangle$ $\langle tl:0, tp:F, th:T, oct \rangle$ $\langle tl:0, tp:F, th:T, oct \rangle$ $\langle tl:1, tp:T, th:T, oct \rangle$ $\langle tl:1, tp:F, th:F, pg \rangle$????? `	6.49 7.85 22.06 35.34 0.61 1.10 2.10 2.54	60.65 78.48 86.84 24.54 21.66 12.21 27.89 12.01
	DRIFT DRIFT DRIFT evDRIFT evDRIFT evDRIFT	\(\lambda t l : 0, \frac{tp : F, th : T, st}\) \(\tau t l : 0, \frac{tp : F, th : T, oct}\) \(\tau t l : 1, \frac{tp : F, th : T, oct}\) \(\tau t l : 0, \frac{tp : F, th : F, pg}\) \(\tau t ! : 0, \frac{tp : F, th : F, pg}\) \(\tau t l : 0, \frac{tp : F, th : F, pg}\) \(\tau t l : 1, \frac{tp : F, th : F, pg}\) \(\ta t l : 1, \frac{tp : F, th : F, pg}\) \(\tau t l : 1, \frac{tp : F, th : F, th : T, st}\)	????? ` \? ` \	6.49 7.85 22.06 35.34 0.61 1.10 2.10	60.65 78.48 86.84 24.54 21.66 12.21 27.89
	DRIFT DRIFT DRIFT evDRIFT evDRIFT evDRIFT evDRIFT evDRIFT	\(\lambda t l : 0, \frac{tp : F, th : T, st}\) \(\tau t l : 0, \frac{tp : F, th : T, oct}\) \(\tau t l : 1, \frac{tp : F, th : T, oct}\) \(\tau t l : 0, \frac{tp : F, th : F, pg}\) \(\tau t ! : 0, \frac{tp : F, th : F, pg}\) \(\tau t l : 0, \frac{tp : F, th : F, pg}\) \(\tau t l : 1, \frac{tp : F, th : F, pg}\) \(\ta t l : 1, \frac{tp : F, th : F, pg}\) \(\tau t l : 1, \frac{tp : F, th : F, th : T, st}\)	????? ` \? ` \	6.49 7.85 22.06 35.34 0.61 1.10 2.10 2.54 1.08	60.65 78.48 86.84 24.54 21.66 12.21 27.89 12.01 17.46
	DRIFT DRIFT PRIFT evDRIFT evDRIFT evDRIFT evDRIFT evDRIFT evDRIFT evDRIFT	$\langle tl:0, tp:F, th:T, st \rangle$ $\langle tl:0, tp:F, th:T, oct \rangle$ $\langle tl:1, tp:F, th:T, oct \rangle$ $\langle tl:0, tp:F, th:F, pg \rangle$ $\langle tl:0, tp:F, th:F, pg \rangle$ $\langle tl:0, tp:F, th:F, pg \rangle$ $\langle tl:1, tp:T, th:T, oct \rangle$ $\langle tl:1, tp:F, th:F, pg \rangle$ $\langle tl:1, tp:F, th:T, st \rangle$	·······	6.49 7.85 22.06 35.34 0.61 1.10 2.10 2.54 1.08 1.03	60.65 78.48 86.84 24.54 21.66 12.21 27.89 12.01 17.46 15.55
	DRIFT DRIFT DRIFT evDRIFT evDRIFT evDRIFT evDRIFT evDRIFT evDRIFT evDRIFT	\(\lambda(tl:0, \frac{tp:F, th:T, st}\)\(\tautrule(tl:0, tp:F, th:T, oct}\)\(\tautrule(tl:1, tp:F, th:T, oct}\)\(\tautrule(tl:0, tp:F, th:F, pg)\)\(\tautrule(tl:0, tp:F, th:T, oct}\)\(\tautrule(tl:0, tp:F, th:T, oct}\)\(\tautrule(tl:1, tp:T, th:T, oct}\)\(\tautrule(tl:1, tp:F, th:F, pg)\)\(\tautrule(tl:1, tp:F, th:T, st)\)\(\tautrule(tl:1, tp:T, th:T, ls)\)\(\tautrule(tl:0, tp:F, th:T, ls)\)	?????\?\\\	6.49 7.85 22.06 35.34 0.61 1.10 2.10 2.54 1.08 1.03	60.65 78.48 86.84 24.54 21.66 12.21 27.89 12.01 17.46 15.55
	DRIFT DRIFT PRIFT evDRIFT evDRIFT evDRIFT evDRIFT evDRIFT evDRIFT evDRIFT	$ \begin{array}{l} \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:0,tp:F,th:T,oct\rangle \\ \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:1,tp:F,th:F,pg\rangle \\ \langle tl:0,tp:F,th:F,pg\rangle \\ \langle tl:0,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,oct\rangle \\ \langle tl:1,tp:T,th:T,oct\rangle \\ \langle tl:1,tp:F,th:F,pg\rangle \\ \langle tl:1,tp:F,th:F,sp\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:0,tp:F,th:T,ls\rangle \\ \end{array} $	·······	6.49 7.85 22.06 35.34 0.61 1.10 2.10 2.54 1.08 1.03	60.65 78.48 86.84 24.54 21.66 12.21 27.89 12.01 17.46 15.55
	DRIFT DRIFT DRIFT evDRIFT evDRIFT evDRIFT evDRIFT evDRIFT evDRIFT evDRIFT evDRIFT	$ \begin{array}{l} \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 0, tp : F, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 0, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : T, th : T, oct \rangle \\ \langle tl : 1, tp : F, th : F, pg \rangle \\ \langle tl : 1, tp : F, th : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, $???????	6.49 7.85 22.06 35.34 0.61 1.10 2.10 2.54 1.08 1.03 0.39 2.02	60.65 78.48 86.84 24.54 21.66 12.21 27.89 12.01 17.46 15.55 13.11 22.56
	DRIFT DRIFT DRIFT evDRIFT	$\langle tl:0, tp:F, th:T, st \rangle$ $\langle tl:0, tp:F, th:T, oct \rangle$ $\langle tl:1, tp:F, th:T, oct \rangle$ $\langle tl:0, tp:F, th:F, pg \rangle$ $\langle tl:0, tp:F, th:F, pg \rangle$ $\langle tl:1, tp:F, th:T, oct \rangle$ $\langle tl:1, tp:F, th:F, pg \rangle$ $\langle tl:1, tp:F, th:T, st \rangle$ $\langle tl:1, tp:F, th:T, ls \rangle$ $\langle tl:1, tp:F, th:T, ls \rangle$ $\langle tl:1, tp:F, th:T, ls \rangle$ $\langle tl:1, tp:F, th:T, st \rangle$ $\langle tl:1, tp:F, th:T, st \rangle$?????\?\\\	6.49 7.85 22.06 35.34 0.61 1.10 2.54 1.08 1.03 0.39 2.02 0.44	60.65 78.48 86.84 24.54 21.66 12.21 27.89 12.01 17.46 15.55 13.11 22.56 15.07
	DRIFT DRIFT DRIFT evDRIFT	$\langle tl:0, tp:F, th:T, st \rangle$ $\langle tl:0, tp:F, th:T, oct \rangle$ $\langle tl:1, tp:F, th:T, oct \rangle$ $\langle tl:0, tp:F, th:F, pg \rangle$ $\langle tl:0, tp:F, th:F, pg \rangle$ $\langle tl:1, tp:T, th:T, oct \rangle$ $\langle tl:1, tp:T, th:T, st \rangle$ $\langle tl:1, tp:F, th:T, st \rangle$?????\?\\\	6.49 7.85 22.06 35.34 0.61 1.10 2.54 1.08 1.03 0.39 2.02 0.44 2.63	60.65 78.48 86.84 24.54 21.66 12.21 27.89 12.01 17.46 15.55 13.11 22.56 15.07 13.75
	DRIFT DRIFT DRIFT evDRIFT	\(\lambda(tl:0, \pip:F, th:T, st\)\(\tau(tl:0, tp:F, th:T, oct\)\(\lambda(tl:1, tp:F, th:T, oct\)\(\tau(tl:0, tp:F, th:F, pg\)\(\tau(tl:0, tp:F, th:F, pg\)\(\tau(tl:0, tp:F, th:F, pg\)\(\tau(tl:1, tp:F, th:F, pg\)\(\tau(tl:1, tp:F, th:F, pg\)\(\tau(tl:1, tp:F, th:T, st\)\(\tau(tl:1, tp:F, th:T, ls\)\(\tau(tl:1, tp:F, th:T, ls\)\(\tau(tl:1, tp:F, th:T, oct\)\(\tau(tl:1, tp:F, th:T, ls\)\(\tau(tl:1, tp:F, th:T, st\)\(\tau(tl:1, tp:F, th:T, st\)\(\tau(tl:1, tp:F, th:T, st\)\(\tau(tl:1, tp:F, th:T, st\)\(\tau(tl:1, tp:F, th:T, ts\)\(\tau(tl:1, tp:F, th:T, ts\)\)	?????\?\\\	6.49 7.85 22.06 35.34 0.61 1.10 2.54 1.08 1.03 0.39 2.02 0.44	60.65 78.48 86.84 24.54 21.66 12.21 27.89 12.01 17.46 15.55 13.11 22.56 15.07
	DRIFT DRIFT DRIFT evDRIFT	\(\lambda(tl:0, \pip:F, th:T, st\)\(\tau(tl:0, tp:F, th:T, oct\)\(\lambda(tl:1, tp:F, th:T, oct\)\(\tau(tl:0, tp:F, th:F, pg\)\(\tau(tl:0, tp:F, th:F, pg\)\(\tau(tl:0, tp:F, th:F, pg\)\(\tau(tl:1, tp:F, th:F, pg\)\(\tau(tl:1, tp:F, th:F, pg\)\(\tau(tl:1, tp:F, th:T, st\)\(\tau(tl:1, tp:F, th:T, ls\)\(\tau(tl:1, tp:F, th:T, ls\)\(\tau(tl:1, tp:F, th:T, oct\)\(\tau(tl:1, tp:F, th:T, ls\)\(\tau(tl:1, tp:F, th:T, st\)\(\tau(tl:1, tp:F, th:T, st\)\(\tau(tl:1, tp:F, th:T, st\)\(\tau(tl:1, tp:F, th:T, st\)\(\tau(tl:1, tp:F, th:T, ts\)\(\tau(tl:1, tp:F, th:T, ts\)\)	?????\?\\\	6.49 7.85 22.06 35.34 0.61 1.10 2.54 1.08 1.03 0.39 2.02 0.44 2.63 0.97	60.65 78.48 86.84 21.66 12.21 27.89 12.01 17.46 15.55 13.11 22.56 15.07 13.75 14.97
17 soots	DRIFT DRIFT DRIFT evDRIFT	$\langle tl:0, tp:F, th:T, st \rangle$ $\langle tl:0, tp:F, th:T, oct \rangle$ $\langle tl:1, tp:F, th:T, oct \rangle$ $\langle tl:0, tp:F, th:F, pg \rangle$ $\langle tl:0, tp:F, th:F, pg \rangle$ $\langle tl:1, tp:T, th:T, oct \rangle$ $\langle tl:1, tp:T, th:T, st \rangle$ $\langle tl:1, tp:F, th:T, st \rangle$???????>>	6.49 7.85 22.06 35.34 0.61 1.10 2.54 1.08 1.03 0.39 2.02 0.44 2.63	60.65 78.48 86.84 24.54 21.66 12.21 27.89 12.01 17.46 15.55 13.11 22.56 15.07 13.75
17. reentr	DRIFT DRIFT DRIFT EVDRIFT	$\langle tl:0, tp:F, th:T, st \rangle$ $\langle tl:0, tp:F, th:T, oct \rangle$ $\langle tl:1, tp:F, th:T, oct \rangle$ $\langle tl:0, tp:F, th:F, pg \rangle$ $\langle tl:0, tp:F, th:F, pg \rangle$ $\langle tl:1, tp:T, th:T, oct \rangle$ $\langle tl:1, tp:F, th:F, pg \rangle$ $\langle tl:1, tp:F, th:F, pg \rangle$ $\langle tl:1, tp:F, th:T, st \rangle$ $\langle tl:1, tp:F, th:T, ls \rangle$ $\langle tl:0, tp:F, th:T, ls \rangle$ $\langle tl:1, tp:F, th:T, st \rangle$ $\langle tl:1, tp:F, th:T, ts \rangle$ $\langle tl:1, tp:F, th:T, ts \rangle$?????\?\\\?\\\	6.49 7.85 22.06 35.34 0.61 1.10 2.54 1.03 0.39 2.02 0.44 2.63 0.97 1.20	60.65 78.48 86.84 24.54 21.66 12.21 27.89 12.01 17.46 15.55 13.11 22.56 15.07 13.75 14.97 18.04
17. reentr	DRIFT DRIFT DRIFT evDRIFT	\(\lambda(tl:0, \pip:F, th:T, st\)\(\tau(tl:0, tp:F, th:T, oct\)\(\lambda(tl:1, tp:F, th:T, oct\)\(\tau(tl:0, tp:F, th:F, pg\)\(\tau(tl:0, tp:F, th:F, pg\)\(\tau(tl:0, tp:F, th:F, pg\)\(\tau(tl:1, tp:F, th:F, pg\)\(\tau(tl:1, tp:F, th:F, pg\)\(\tau(tl:1, tp:F, th:T, st\)\(\tau(tl:1, tp:F, th:T, ls\)\(\tau(tl:1, tp:F, th:T, ls\)\(\tau(tl:1, tp:F, th:T, oct\)\(\tau(tl:1, tp:F, th:T, ls\)\(\tau(tl:1, tp:F, th:T, st\)\(\tau(tl:1, tp:F, th:T, st\)\(\tau(tl:1, tp:F, th:T, st\)\(\tau(tl:1, tp:F, th:T, st\)\(\tau(tl:1, tp:F, th:T, ts\)\(\tau(tl:1, tp:F, th:T, ts\)\)	?????\?\\\?\\\\?\\\\?	6.49 7.85 22.06 35.34 0.61 1.10 2.54 1.08 1.03 0.39 2.02 0.44 2.63 0.97	60.65 78.48 86.84 24.54 21.66 12.21 17.46 15.55 13.11 22.56 15.07 13.75 14.97 18.04
17. reentr	DRIFT DRIFT DRIFT evDRIFT	\(\lambda(tl:0, \lambda p:F, th:T, st\)\(\tau(tl:0, tp:F, th:T, oct\)\(\tau(tl:1, tp:F, th:T, oct\)\(\tau(tl:0, tp:F, th:F, pg\)\(\tau(tl:0, tp:F, th:F, pg\)\(\tau(tl:0, tp:F, th:F, pg\)\(\tau(tl:1, tp:F, th:F, pg\)\(\tau(tl:1, tp:F, th:F, pg\)\(\tau(tl:1, tp:F, th:T, st\)\(\tau(tl:1, tp:F, th:T, ls\)\(\tau(tl:1, tp:F, th:T, ls\)\(\tau(tl:1, tp:F, th:T, ls\)\(\tau(tl:1, tp:F, th:T, st\)\(\tau(tl:1, tp:F, th:T, st\)\(\tau(tl:1, tp:F, th:T, st\)\(\tau(tl:1, tp:F, th:T, st\)\(\tau(tl:1, tp:F, th:T, ts\)\(\tau(tl:1, tp:F, th:T, ts\)\(\tau(tl:1, tp:F, th:T, ts\)\(\tau(tl:1, tp:F, th:T, st\)\(\tau(tl:1, tp:T, th:T, st\)\(\t	?????\?\\\?\\\\?\\\\?	6.49 7.85 22.06 35.34 0.61 1.10 2.54 1.08 1.03 0.39 2.02 0.44 2.63 0.97 1.20	60.65 78.48 86.84 24.54 21.66 12.21 17.46 15.55 13.11 22.56 15.07 13.75 14.97 18.04
17. reentr	DRIFT DRIFT DRIFT evDRIFT DRIFT DRIFT	\(\lambda(tl:0, \lambda(p:F, th:T, st)\)\(\tau(tl:0, tp:F, th:T, oct)\\(\tau(tl:1, tp:F, th:F, pg)\)\(\tau(tl:0, tp:F, th:F, pg)\\(\tau(tl:0, tp:F, th:F, pg)\)\(\tau(tl:0, tp:F, th:F, pg)\\(\tau(tl:1, tp:F, th:F, pg)\)\(\tau(tl:1, tp:F, th:T, st)\\(\tau(tl:1, tp:F, th:T, st)\)\(\tau(tl:1, tp:F, th:T, ls)\\(\tau(tl:1, tp:F, th:T, st)\)\(\tau(tl:1, tp:F, th:T, st)\\(\tau(tl:1, tp:F, th:T, st)\)\(\tau(tl:1, tp:F, th:T, st)\\(\tau(tl:1, tp:F, th:T, st)\)\\(\tau(tl:1, tp:F, th:T, st)\\\(\tau(tl:1, tp:F, th:T, st)\\\(\tau(tl:1, tp:F, th:T, st)\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\	?????\?\\\?\\\\	6.49 7.85 22.06 35.34 0.61 1.10 2.54 1.08 1.03 0.39 2.02 0.44 2.63 0.97 1.20	60.65 78.48 86.84 24.54 21.66 12.21 27.89 12.01 17.46 15.55 13.11 22.56 15.07 13.75 14.97 18.04
17. reentr	DRIFT DRIFT DRIFT evDRIFT bvDRIFT evDRIFT DRIFT DRIFT DRIFT	$\langle tl:0, tp:F, th:T, st \rangle$ $\langle tl:0, tp:F, th:T, oct \rangle$ $\langle tl:1, tp:F, th:T, oct \rangle$ $\langle tl:1, tp:F, th:F, pg \rangle$ $\langle tl:0, tp:F, th:F, pg \rangle$ $\langle tl:0, tp:F, th:T, oct \rangle$ $\langle tl:1, tp:F, th:T, oct \rangle$ $\langle tl:1, tp:F, th:F, pg \rangle$ $\langle tl:1, tp:F, th:T, st \rangle$ $\langle tl:1, tp:F, th:T, st \rangle$ $\langle tl:1, tp:F, th:T, ls \rangle$ $\langle tl:1, tp:F, th:T, st \rangle$ $\langle tl:1, tp:F, th:T, st \rangle$ $\langle tl:1, tp:F, th:T, st \rangle$ $\langle tl:1, tp:F, th:T, ts \rangle$ $\langle tl:1, tp:F, th:T, ts \rangle$ $\langle tl:1, tp:F, th:T, ts \rangle$ $\langle tl:1, tp:F, th:T, st \rangle$?????\?\\\?\\\\	6.49 7.85 22.06 35.34 0.61 1.10 2.10 2.54 1.08 1.03 0.39 2.02 0.44 2.63 0.97 1.20	60.65 78.48 86.84 24.54 21.66 12.21 27.89 12.01 17.46 15.55 13.11 22.56 15.07 13.75 14.97 18.04 57.29 21.20 24.30
17. reentr	DRIFT DRIFT DRIFT evDRIFT DRIFT DRIFT	\(\lambda(tl:0, \lambda(p:F, th:T, st)\)\(\lambda(tl:0, tp:F, th:T, oct)\)\(\lambda(tl:1, tp:F, th:F, pg)\)\(\lambda(tl:0, tp:F, th:F, pg)\)\(\lambda(tl:0, tp:F, th:F, pg)\)\(\lambda(tl:1, tp:F, th:F, pg)\)\(\lambda(tl:1, tp:F, th:T, st)\)\(\lambda(tl:1, tp:F, th:T, ls)\)\(\lambda(tl:1, tp:F, th:T, ls)\)\(\lambda(tl:1, tp:F, th:T, ls)\)\(\lambda(tl:1, tp:F, th:T, st)\)\(\lambda(tl:1, tp:T, th:T, tls)\)	?????\?\\\\?\\\\\\\\\\\\\\\\\\\\\\\\\\	6.49 7.85 22.06 35.34 0.61 1.10 2.54 1.03 0.39 2.02 0.44 2.63 0.97 1.20 67.19 9.63 10.60 53.82	60.65 78.48 86.84 24.54 21.66 12.21 27.89 12.01 17.46 15.55 13.11 22.56 15.07 13.75 14.97 18.04
17. reentr	DRIFT DRIFT DRIFT evDRIFT DRIFT DRIFT DRIFT	\(\lambda(tl:0, \lambda(p:F, th:T, st)\) \(\lambda(tl:0, tp:F, th:T, oct)\) \(\lambda(tl:1, tp:F, th:F, pg)\) \(\lambda(tl:0, tp:F, th:F, pg)\) \(\lambda(tl:0, tp:F, th:F, pg)\) \(\lambda(tl:1, tp:F, th:F, pg)\) \(\lambda(tl:1, tp:F, th:T, st)\) \(\lambda(tl:1, tp:F, th:T, ls)\) \(\lambda(tl:1, tp:F, th:T, ls)\) \(\lambda(tl:1, tp:F, th:T, ls)\) \(\lambda(tl:1, tp:F, th:T, st)\)	?????\?\\\\?\\\\\\\\\\\\\\\\\\\\\\\\\\	6.49 7.85 22.06 35.34 0.61 1.10 2.54 1.03 0.39 2.02 0.44 2.63 0.97 1.20 67.19 9.63 10.60 53.82	60.65 78.48 86.84 24.54 21.66 12.21 27.89 12.01 17.46 15.55 13.11 22.56 15.07 13.75 14.97 18.04 57.29 21.20 24.30 46.31
17. reentr	DRIFT DRIFT DRIFT evDRIFT evDRIFT evDRIFT evDRIFT evDRIFT evDRIFT evDRIFT evDRIFT evDRIFT DRIFT DRIFT DRIFT DRIFT DRIFT	\(\lambda(tl:0, \lambda(p:F, th:T, st)\) \(\lambda(tl:0, tp:F, th:T, oct)\) \(\lambda(tl:1, tp:F, th:F, pg)\) \(\lambda(tl:0, tp:F, th:F, pg)\) \(\lambda(tl:0, tp:F, th:F, pg)\) \(\lambda(tl:1, tp:F, th:F, pg)\) \(\lambda(tl:1, tp:F, th:F, pg)\) \(\lambda(tl:1, tp:F, th:T, st)\) \(\lambda(tl:1, tp:F, th:T, ls)\) \(\lambda(tl:1, tp:F, th:T, ls)\) \(\lambda(tl:1, tp:F, th:T, st)\) \(\lambda(tl:1, tp:F, th:T, st)\) \(\lambda(tl:1, tp:F, th:T, ls)\) \(\lambda(tl:1, tp:F, th:T, ls)\) \(\lambda(tl:1, tp:F, th:T, st)\) \(\lambda(tl:1, tp:F, th:T, ls)\) \(\lambda(tl:1, tp:T, th:T, ls)\) \(\lambda(tl:1, tp:T, th:T, ls)\) \(\lambda(tl:1, tp:T, th:T, ls)\)	???????>>>>>?	6.49 7.85 22.06 35.34 0.61 1.10 2.54 1.08 1.03 0.39 2.02 0.44 2.63 0.97 1.20	60.65 78.48 86.84 24.54 21.66 12.21 17.46 15.55 13.11 22.56 15.07 13.75 14.97 18.04 57.29 21.20 24.30 46.31 149.69
17. reentr	DRIFT DRIFT DRIFT evDRIFT DRIFT DRIFT DRIFT	\(\lambda(tl:0, \lambda(p:F, th:T, st)\) \(\lambda(tl:0, tp:F, th:T, oct)\) \(\lambda(tl:1, tp:F, th:F, pg)\) \(\lambda(tl:0, tp:F, th:F, pg)\) \(\lambda(tl:0, tp:F, th:F, pg)\) \(\lambda(tl:1, tp:F, th:F, pg)\) \(\lambda(tl:1, tp:F, th:T, st)\) \(\lambda(tl:1, tp:F, th:T, ls)\) \(\lambda(tl:1, tp:F, th:T, ls)\) \(\lambda(tl:1, tp:F, th:T, ls)\) \(\lambda(tl:1, tp:F, th:T, st)\)	?????\?\\\\?\\\\\\\\\\\\\\\\\\\\\\\\\\	6.49 7.85 22.06 35.34 0.61 1.10 2.54 1.03 0.39 2.02 0.44 2.63 0.97 1.20 67.19 9.63 10.60 53.82	60.65 78.48 86.84 24.54 21.66 12.21 27.89 12.01 17.46 15.55 13.11 22.56 15.07 13.75 14.97 18.04 57.29 21.20 24.30 46.31

Ì	Drift	1/+1-1 +p.F +h.T oct\1	./	28.68	76.53
		$\langle tl:1, tp:F, th:T, oct \rangle$	•		
	Drift	$\langle tl:0, tp:F, th:T, oct \rangle$?	22.11	62.88
	Drift	$\langle tl:0, tp:F, th:F, pq \rangle$?	28.54	20.92
	Drift	$\langle tl:0,tp:F,th:T,ls\rangle$?	29.43	129.15
			?		
	Drift	$\langle tl:1, tp:T, th:F, pg \rangle$	٠,	98.66	46.60
	Drift	$\langle tl:1, tp:F, th:F, pg \rangle$	~	21.36	24.33
	evDrift		?	1.80	23.39
	evDrift	$\langle tl:1, tp:F, th:F, pg \rangle$	V	0.59	9.99
	evDrift	$\langle tl:1, tp:F, th:T, st \rangle$	~	0.48	13.12
	ev Drift	$\langle tl:1, tp:T, th:T, ls \rangle$	~	0.45	11.21
	evDrift	$\langle tl:0, tp:F, th:T, ls \rangle$		0.58	14.31
	_		?		
	evDrift		ſ	1.33	17.01
	evDrift	$\langle tl:0, tp:F, th:F, pq \rangle$?	0.65	9.78
	evDrift	$\langle tl:1, tp:F, th:T, ls \rangle$	~	0.40	11.03
	evDrift	$\langle tl:1, tp:T, th:T, st \rangle$	~	0.52	12.92
	evDrift	$\langle tl:0,tp:F,th:T,st\rangle$?	0.70	17.33
	ev Drift	$\langle tl:1, tp:F, th:T, oct \rangle$?	1.75	23.40
	evDrift	$\langle tl:1, tp:T, th:F, pg \rangle$	~	0.60	9.86
10 manauman amaluaia	CVDIGIT	\tt.1, tp.1, tm.1, pg/	<u> </u>	0.00	7.00
18. resource-analysis	n	1/11 4 1. 77 11 77 1			04.00
	Drift	$\langle tl:1, tp:T, th:T, ls \rangle$		7.64	24.20
	Drift	$\langle tl:1, tp:F, th:T, st \rangle$	~	7.25	27.59
	Drift	$\langle tl:1, tp:F, th:T, ls \rangle$	1	6.85	24.04
	I_		~		
	DRIFT	$\langle tl:1, tp:T, th:T, st \rangle$		8.40	27.15
	Drift	$\langle tl:1, tp:T, th:F, pg \rangle$	~	21.00	25.58
	Drift	$\langle tl:1, tp:F, th:F, pq \rangle$	~	21.26	23.88
	Drift	$\langle tl:0,tp:F,th:T,ls\rangle$?	6.73	26.81
	I_	/+1.0 +p.F +h.T c+\	•		
	DRIFT	$\langle tl:0, tp:F, th:T, st \rangle$?	7.56	31.53
	Drift	$\langle tl:0, tp:F, th:F, pg \rangle$?	13.13	17.53
	Drift	$\langle tl:1, tp:F, th:T, oct \rangle$	~	12.80	59.78
	Drift	$\langle tl:0, tp:F, th:T, oct \rangle$?	9.25	54.78
	Drift	$\langle tl:1, tp:T, th:T, oct \rangle$?	14.11	63.10
	evDrift		•	0.54	10.40
	_	$\langle tl:0, tp:F, th:F, pg \rangle$	•		
	evDrift	' !	? ? •	0.32	9.67
	evDrift	$\langle tl:1, tp:T, th:T, ls \rangle$	~	0.40	9.89
	ev Drift	$\langle tl:0, tp:F, th:T, ls \rangle$?	0.31	9.02
	ev Drift	$\langle tl:1, tp:F, th:F, pq \rangle$	~	0.76	10.53
	evDrift		1	0.56	11.51
	_		V		11.92
	evDrift	$\langle tl:1, tp:F, th:T, st \rangle$		0.47	
	evDrift	$\langle tl:1, tp:T, th:F, pg \rangle$	~	0.77	11.16
	evDRIFT evDRIFT	$\langle tl:1, tp:T, th:F, pg \rangle$ $\langle tl:1, tp:F, th:T, oct \rangle$	~	0.51	11.16 11.37
	_				
	evDrift evDrift	$\langle tl:1, tp:F, th:T, oct \rangle$ $\langle tl:0, tp:F, th:T, st \rangle$	~	0.51 0.35	11.37 10.07
	evDrift evDrift evDrift	$\langle tl:1, tp:F, th:T, oct \rangle$ $\langle tl:0, tp:F, th:T, st \rangle$ $\langle tl:1, tp:F, th:T, ls \rangle$?	0.51 0.35 0.35	11.37 10.07 10.21
19 sum-annendix	evDrift evDrift	$\langle tl:1, tp:F, th:T, oct \rangle$ $\langle tl:0, tp:F, th:T, st \rangle$?	0.51 0.35	11.37 10.07
19. sum-appendix	evDrift evDrift evDrift evDrift	$ \begin{array}{l} \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \end{array} $?	0.51 0.35 0.35 0.54	11.37 10.07 10.21 11.59
19. sum-appendix	evDrift evDrift evDrift evDrift Drift	$ \begin{aligned} &\langle tl:1, tp:F, th:T, oct \rangle \\ &\langle tl:0, tp:F, th:T, st \rangle \\ &\langle tl:1, tp:F, th:T, ls \rangle \\ &\langle tl:1, tp:T, th:T, st \rangle \end{aligned} $	ソ ? ソ ソ	0.51 0.35 0.35 0.54	11.37 10.07 10.21 11.59 27.86
19. sum-appendix	evDrift evDrift evDrift evDrift	$ \begin{array}{l} \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \end{array} $	> ? V V V V V	0.51 0.35 0.35 0.54 8.16 9.29	11.37 10.07 10.21 11.59
19. sum-appendix	evDrift evDrift evDrift evDrift Drift	$ \begin{aligned} &\langle tl:1, tp:F, th:T, oct \rangle \\ &\langle tl:0, tp:F, th:T, st \rangle \\ &\langle tl:1, tp:F, th:T, ls \rangle \\ &\langle tl:1, tp:T, th:T, st \rangle \end{aligned} $	ソマンソソソ	0.51 0.35 0.35 0.54	11.37 10.07 10.21 11.59 27.86
19. sum-appendix	evDrift evDrift evDrift evDrift Drift Drift	$ \begin{array}{l} \langle tl : 1, tp : F, th : T, oct \rangle \\ \langle tl : 0, tp : F, th : T, st \rangle \\ \langle tl : 1, tp : F, th : T, ls \rangle \\ \langle tl : 1, tp : T, th : T, st \rangle \\ \end{array} $	ソマンソソソ	0.51 0.35 0.35 0.54 8.16 9.29 8.31	11.37 10.07 10.21 11.59 27.86 31.18 27.88
19. sum-appendix	evDrift evDrift evDrift evDrift Drift Drift Drift Drift	$ \begin{aligned} &\langle tl : 1, tp : F, th : T, oct \rangle \\ &\langle tl : 0, tp : F, th : T, st \rangle \\ &\langle tl : 1, tp : F, th : T, ls \rangle \\ &\langle tl : 1, tp : T, th : T, st \rangle \end{aligned} \\ &\langle tl : 1, tp : F, th : T, ls \rangle \\ &\langle tl : 1, tp : T, th : T, st \rangle \\ &\langle tl : 1, tp : T, th : T, st \rangle \\ &\langle tl : 1, tp : T, th : T, ls \rangle \\ &\langle tl : 1, tp : T, th : T, st \rangle \end{aligned}$	ソ?ソソソソソ	0.51 0.35 0.35 0.54 8.16 9.29 8.31 8.77	11.37 10.07 10.21 11.59 27.86 31.18 27.88 31.18
19. sum-appendix	evDrift evDrift evDrift evDrift Drift Drift Drift Drift Drift Drift Drift	$ \begin{array}{l} \langle tl:1,tp:F,th:T,oct \rangle \\ \langle tl:0,tp:F,th:T,st \rangle \\ \langle tl:1,tp:F,th:T,ls \rangle \\ \langle tl:1,tp:F,th:T,st \rangle \\ \end{array} \\ \begin{array}{l} \langle tl:1,tp:F,th:T,st \rangle \\ \\ \langle tl:1,tp:T,th:T,st \rangle \\ \end{array} \\ \begin{array}{l} \langle tl:1,tp:T,th:T,st \rangle \\ \langle tl:1,tp:T,th:T,st \rangle \\ \langle tl:1,tp:F,th:T,st \rangle \\ \langle tl:1,tp:F,th:T,st \rangle \\ \langle tl:1,tp:F,th:T,oct \rangle \\ \end{array}$	ソ?ソソソソソソ	0.51 0.35 0.35 0.54 8.16 9.29 8.31 8.77 53.57	11.37 10.07 10.21 11.59 27.86 31.18 27.88 31.18 154.83
19. sum-appendix	evDrift evDrift evDrift evDrift Drift	$ \begin{array}{l} \langle tl:1,tp:F,th:T,oct \rangle \\ \langle tl:0,tp:F,th:T,st \rangle \\ \langle tl:1,tp:F,th:T,ls \rangle \\ \langle tl:1,tp:T,th:T,st \rangle \\ \\ \langle tl:1,tp:T,th:T,st \rangle \\ \langle tl:1,tp:T,th:T,st \rangle \\ \langle tl:1,tp:F,th:T,st \rangle \\ \langle tl:1,tp:F,th:T,oct \rangle \\ \langle tl:1,tp:F,th:T,oct \rangle \\ \langle tl:0,tp:F,th:T,oct \rangle \\ \langle tl:0,tp:F,th:T,oct \rangle \\ \langle tl:0,tp:F,th:T,oct \rangle \\ \end{array} $	ソ?ソソソソソソ	0.51 0.35 0.35 0.54 8.16 9.29 8.31 8.77 53.57 40.07	11.37 10.07 10.21 11.59 27.86 31.18 27.88 31.18 154.83 126.93
19. sum-appendix	evDrift evDrift evDrift evDrift Drift	$ \begin{array}{l} \langle tl:1,tp:F,th:T,oct \rangle \\ \langle tl:0,tp:F,th:T,st \rangle \\ \langle tl:1,tp:F,th:T,ls \rangle \\ \langle tl:1,tp:F,th:T,st \rangle \\ \end{array} \\ \begin{array}{l} \langle tl:1,tp:F,th:T,st \rangle \\ \langle tl:1,tp:T,th:T,st \rangle \\ \langle tl:1,tp:T,th:T,st \rangle \\ \langle tl:1,tp:F,th:T,oct \rangle \\ \langle tl:1,tp:F,th:T,oct \rangle \\ \langle tl:0,tp:F,th:T,gp \rangle \\ \langle tl:0,tp:F,th:T,pp \rangle \end{array}$	ソ?ソソソソソソ	0.51 0.35 0.35 0.54 8.16 9.29 8.31 8.77 53.57 40.07 62.75	11.37 10.07 10.21 11.59 27.86 31.18 27.88 31.18 154.83 126.93 26.42
19. sum-appendix	evDrift evDrift evDrift evDrift Drift	$ \begin{array}{l} \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \end{array} \\ \begin{array}{l} \langle tl:1,tp:F,th:T,s\rangle \\ \langle tl:1,tp:F,th:T,s\rangle \\ \langle tl:1,tp:T,th:T,s\rangle \\ \langle tl:1,tp:F,th:T,s\rangle \\ \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:F,pg\rangle \\ \langle tl:0,tp:F,th:F,s\rangle \\ \langle tl:0,tp:F,th:T,s\rangle \\ \end{array} $	ソ?ソソソソソソ	0.51 0.35 0.35 0.54 8.16 9.29 8.31 8.77 53.57 40.07	11.37 10.07 10.21 11.59 27.86 31.18 27.88 31.18 154.83 126.93
19. sum-appendix	evDrift evDrift evDrift evDrift Drift	$ \begin{array}{l} \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \end{array} \\ \begin{array}{l} \langle tl:1,tp:F,th:T,s\rangle \\ \langle tl:1,tp:F,th:T,s\rangle \\ \langle tl:1,tp:T,th:T,s\rangle \\ \langle tl:1,tp:F,th:T,s\rangle \\ \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:F,pg\rangle \\ \langle tl:0,tp:F,th:F,s\rangle \\ \langle tl:0,tp:F,th:T,s\rangle \\ \end{array} $	\?\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\	0.51 0.35 0.35 0.54 8.16 9.29 8.31 8.77 53.57 40.07 62.75	11.37 10.07 10.21 11.59 27.86 31.18 27.88 31.18 154.83 126.93 26.42
19. sum-appendix	evDrift evDrift evDrift evDrift Drift	$ \begin{array}{l} \langle tl:1, tp:F, th:T, oct \rangle \\ \langle tl:0, tp:F, th:T, st \rangle \\ \langle tl:1, tp:F, th:T, ls \rangle \\ \langle tl:1, tp:F, th:T, ls \rangle \\ \langle tl:1, tp:T, th:T, st \rangle \\ \end{array} $	\?\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\	0.51 0.35 0.35 0.54 8.16 9.29 8.31 8.77 53.57 40.07 62.75 19.39 54.08	11.37 10.07 10.21 11.59 27.86 31.18 27.88 31.18 154.83 126.93 26.42 76.48 154.80
19. sum-appendix	evDrift evDrift evDrift evDrift Drift	$ \begin{array}{l} \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \end{array} $	\?\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\	0.51 0.35 0.35 0.54 8.16 9.29 8.31 8.77 53.57 40.07 62.75 19.39 54.08 15.11	11.37 10.07 10.21 11.59 27.86 31.18 27.88 31.18 154.83 126.93 26.42 76.48 154.80 54.33
19. sum-appendix	evDRIFT evDRIFT evDRIFT DRIFT	$ \begin{array}{l} \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,ot\rangle \\ \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1,tp:T,th:F,pg\rangle \\ \end{array}$	\?\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\	0.51 0.35 0.35 0.54 8.16 9.29 8.31 8.77 53.57 40.07 62.75 19.39 54.08 15.11 57.51	11.37 10.07 10.21 11.59 27.86 31.18 27.88 31.18 154.83 126.93 26.42 76.48 154.80 54.33 34.43
19. sum-appendix	evDRIFT evDRIFT evDRIFT DRIFT	$ \begin{array}{l} \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \end{array} \\ \begin{array}{l} \langle tl:1,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:T,th:F,pg\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:T,th:F,spg\rangle \\ \langle tl:1,tp:T,th:F,pg\rangle \\ \end{array}$	ソマンソソソソマママンマン	0.51 0.35 0.35 0.54 8.16 9.29 8.31 8.77 53.57 40.07 62.75 19.39 54.08 15.11 57.51 58.62	11.37 10.07 10.21 11.59 27.86 31.18 27.88 31.18 154.83 126.93 26.42 76.48 154.80 54.33 34.43
19. sum-appendix	evDrift evDrift evDrift evDrift Drift Evipt Drift Drift Drift Drift Drift Drift Drift Drift Drift EvDrift	$ \begin{array}{l} \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \end{array} \\ \begin{array}{l} \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1,tp:T,th:F,pg\rangle \\ \langle tl:1,tp:T,th:F,pg\rangle \\ \langle tl:1,tp:T,th:F,pg\rangle \\ \langle tl:1,tp:F,th:F,tls\rangle \\ \end{array}$	\?\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\	0.51 0.35 0.35 0.54 8.16 9.29 8.31 8.77 53.57 40.07 62.75 19.39 54.08 15.11 57.51 58.62 0.05	11.37 10.07 10.21 11.59 27.86 31.18 27.88 31.18 154.83 126.93 26.42 154.80 54.33 34.43 34.43 6.97
19. sum-appendix	evDRIFT evDRIFT evDRIFT DRIFT	$ \begin{array}{l} \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \end{array} \\ \begin{array}{l} \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1,tp:T,th:F,pg\rangle \\ \langle tl:1,tp:T,th:F,pg\rangle \\ \langle tl:1,tp:T,th:F,pg\rangle \\ \langle tl:1,tp:F,th:F,tls\rangle \\ \end{array}$	ソマンソソソソマママンマン	0.51 0.35 0.35 0.54 8.16 9.29 8.31 8.77 53.57 40.07 62.75 19.39 54.08 15.11 57.51 58.62	11.37 10.07 10.21 11.59 27.86 31.18 27.88 31.18 154.83 126.93 26.42 76.48 154.80 54.33 34.43
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19. sum-appendix	evDrift evDrift evDrift evDrift Drift EvDrift Drift Drift Drift Drift Drift EvDrift	$ \begin{array}{l} \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:T,th:F,pg\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:T,th:F,pg\rangle \\ \langle tl:1,tp:T,th:F,pg\rangle \\ \langle tl:1,tp:F,th:F,ls\rangle \\ \langle tl:1,tp:F,th:F,pg\rangle \\ \langle tl:1,tp:F,th:F,pg\rangle \\ \langle tl:1,tp:F,th:F,pg\rangle \\ \langle tl:1,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:F,pg\rangle \\ \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:1,tp:F,th:T,oct$	\?\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\	0.51 0.35 0.54 8.16 9.29 8.31 8.77 53.57 40.07 62.75 19.39 54.08 15.11 57.51 58.62 0.05 0.04 0.04 0.05 0.11	11.37 10.07 10.21 11.59 27.86 31.18 27.88 31.18 154.83 126.93 26.42 76.48 154.80 54.33 34.43 34.43 34.43 6.97 6.05 6.84 6.05
19. sum-appendix	evDrift evDrift evDrift evDrift Drift EvDrift	$ \begin{array}{l} \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:T,th:F,pg\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1,tp:T,th:T,sp\rangle \\ \langle tl:1,tp:T,th:T,ls\rangle \\ \langle tl:1,tp:T,th:T,ls\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:1,tp:F,th:T,sp\rangle \\ \langle tl:0,tp:F,th:T,oct\rangle \\ \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1,tp:T,tt:T,st\rangle \\ \langle tl:1,tp:T,tt:T,st\rangle \\ \langle tl:1,$	\?\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\	0.51 0.35 0.35 0.54 8.16 9.29 8.31 8.77 53.57 40.07 62.75 19.39 54.08 15.11 57.51 58.62 0.05 0.04 0.04 0.05 0.11 0.06 0.16 0.04	11.37 10.07 10.21 11.59 27.86 31.18 27.88 31.18 154.83 126.93 26.42 76.48 154.80 54.33 34.43 34.43 6.97 6.05 6.84 6.05 8.80 6.45 9.07
19. sum-appendix	evDrift evDrift evDrift evDrift Drift EvDrift	$ \begin{array}{l} \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:T,th:F,pg\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:T,th:F,spg\rangle \\ \langle tl:1,tp:T,th:F,pg\rangle \\ \langle tl:1,tp:T,th:F,pg\rangle \\ \langle tl:1,tp:T,th:T,sp\rangle \\ \langle tl:1,tp:T,th:T,sp\rangle \\ \langle tl:1,tp:F,th:T,sp\rangle \\ \langle tl:1,tp:F,th:T,sp\rangle \\ \langle tl:1,tp:F,th:T,sp\rangle \\ \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:1,tp:F,th:F,pg\rangle \\ \langle tl:0,tp:F,th:F,pg\rangle \\ \langle tl:0,tp:F,th:F,pg\rangle \\ \langle tl:0,tp:F,th:T,oct\rangle \\ \langle tl:1,tp:T,th:T,oct\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1,tp:F,th:F,pg\rangle \\ \langle tl:0,tp:F,th:F,pg\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1,tp:T,tt:T,st\rangle \\ \langle tl:$	\?\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\	0.51 0.35 0.54 8.16 9.29 8.31 8.77 53.57 40.07 62.75 19.39 54.08 15.11 57.51 57.51 58.62 0.05 0.04 0.05 0.11 0.06 0.16 0.04	11.37 10.07 10.21 11.59 27.86 31.18 27.88 31.18 154.83 126.93 26.42 76.48 154.80 54.33 34.43 34.43 6.97 6.05 6.84 6.05 8.80 6.45 9.07
19. sum-appendix	evDrift evDrift evDrift evDrift Drift EvDrift	$\langle tl:1, tp:F, th:T, oct \rangle$ $\langle tl:0, tp:F, th:T, st \rangle$ $\langle tl:1, tp:F, th:T, oct \rangle$ $\langle tl:1, tp:F, th:T, oct \rangle$ $\langle tl:0, tp:F, th:T, oct \rangle$ $\langle tl:0, tp:F, th:T, st \rangle$ $\langle tl:0, tp:F, th:T, st \rangle$ $\langle tl:1, tp:T, th:T, st \rangle$ $\langle tl:1, tp:T, th:F, pg \rangle$ $\langle tl:1, tp:F, th:F, pg \rangle$ $\langle tl:1, tp:F, th:T, ls \rangle$ $\langle tl:1, tp:F, th:T, ls \rangle$ $\langle tl:1, tp:F, th:T, ls \rangle$ $\langle tl:1, tp:F, th:T, st \rangle$ $\langle tl:1, tp:F, th:T, oct \rangle$ $\langle tl:1, tp:F, th:F, pg \rangle$ $\langle tl:1, tp:F, th:T, oct \rangle$ $\langle tl:1, tp:F, th:T, st \rangle$	\?\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\	0.51 0.35 0.54 8.16 9.29 8.31 8.77 53.57 40.07 62.75 19.39 54.08 15.11 57.51 58.62 0.05 0.04 0.04 0.05 0.11 0.06 0.16 0.04 0.04	11.37 10.07 10.21 11.59 27.86 31.18 27.88 31.18 154.83 126.93 26.42 76.48 154.80 54.33 34.43 34.43 6.97 6.05 6.84 6.05 6.85 9.07 6.84 6.05 7.88
19. sum-appendix	evDrift evDrift evDrift evDrift Drift EvDrift	$ \begin{array}{l} \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:T,th:F,pg\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:T,th:F,pg\rangle \\ \langle tl:0,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:T,th:F,pg\rangle \\ \langle tl:1,tp:T,th:F,pg\rangle \\ \langle tl:1,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,scr\rangle \\ \langle tl:1,tp:F,th:T,scr\rangle$	\?\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\	0.51 0.35 0.35 0.54 8.16 9.29 8.31 8.77 53.57 40.07 62.75 19.39 54.08 15.11 57.51 58.62 0.05 0.04 0.05 0.11 0.06 0.16 0.04 0.05 0.04	11.37 10.07 10.21 11.59 27.86 31.18 27.88 31.18 154.83 126.93 26.42 76.48 154.80 54.33 34.43 34.43 6.97 6.05 8.80 6.45 9.07 6.84 6.05 7.88 6.05
	evDrift evDrift evDrift evDrift Drift EvDrift	$\langle tl:1, tp:F, th:T, oct \rangle$ $\langle tl:0, tp:F, th:T, st \rangle$ $\langle tl:1, tp:F, th:T, oct \rangle$ $\langle tl:1, tp:F, th:T, oct \rangle$ $\langle tl:0, tp:F, th:T, oct \rangle$ $\langle tl:0, tp:F, th:T, st \rangle$ $\langle tl:0, tp:F, th:T, st \rangle$ $\langle tl:1, tp:T, th:T, st \rangle$ $\langle tl:1, tp:T, th:F, pg \rangle$ $\langle tl:1, tp:F, th:F, pg \rangle$ $\langle tl:1, tp:F, th:T, ls \rangle$ $\langle tl:1, tp:F, th:T, ls \rangle$ $\langle tl:1, tp:F, th:T, ls \rangle$ $\langle tl:1, tp:F, th:T, st \rangle$ $\langle tl:1, tp:F, th:T, oct \rangle$ $\langle tl:1, tp:F, th:F, pg \rangle$ $\langle tl:1, tp:F, th:T, oct \rangle$ $\langle tl:1, tp:F, th:T, st \rangle$	\?\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\	0.51 0.35 0.54 8.16 9.29 8.31 8.77 53.57 40.07 62.75 19.39 54.08 15.11 57.51 58.62 0.05 0.04 0.04 0.05 0.11 0.06 0.16 0.04 0.04	11.37 10.07 10.21 11.59 27.86 31.18 27.88 31.18 154.83 126.93 26.42 76.48 154.80 54.33 34.43 34.43 6.97 6.05 6.84 6.05 6.85 9.07 6.84 6.05 7.88
19. sum-appendix 20. sum-of-ev-even	evDrift evDrift evDrift Drift EvDrift	$ \begin{array}{l} \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:T,th:F,pg\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:T,th:F,st\rangle \\ \langle tl:1,tp:T,th:T,oct\rangle \\ \langle tl:1,tp:T,th:T,oct\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,$	ソ?ソソソソ???ソ?ソソソソソソソソソソソ	0.51 0.35 0.35 0.54 8.16 9.29 8.31 8.77 53.57 40.07 62.75 19.39 54.08 15.11 57.51 57.51 0.04 0.05 0.11 0.06 0.16 0.04 0.05 0.05	11.37 10.07 10.21 11.59 27.86 31.18 27.88 31.18 154.83 126.93 26.42 76.48 154.80 54.33 34.43 34.43 6.97 6.05 6.84 6.05 7.88 6.05 7.88 6.05 8.80
	evDRIFT evDRIFT evDRIFT DRIFT EVDRIFT DRIFT	$ \begin{array}{l} \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:F,pg\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:T,th:F,pg\rangle \\ \langle tl:1,tp:F,th:F,pg\rangle \\ \langle tl:1,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1$	\?\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\	0.51 0.35 0.35 0.54 8.16 9.29 8.31 8.77 53.57 40.07 62.75 19.39 54.08 15.11 57.51 58.62 0.05 0.04 0.05 0.11 0.04 0.04 0.04 0.04 0.05 0.05	11.37 10.07 10.21 11.59 27.86 31.18 27.88 31.18 154.83 26.42 76.48 154.83 34.43 34.43 34.43 6.95 6.84 6.05 8.80 9.07 6.84 6.05 8.84 8.84 8.84 8.84 8.84 8.84 8.84 8.8
	evDrift evDrift evDrift evDrift Drift evDrift Drift evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift	$ \begin{array}{l} \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:T,th:F,pg\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:T,th:F,pg\rangle \\ \langle tl:1,tp:T,th:F,pg\rangle \\ \langle tl:1,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:T,th:F,th:T,st\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1$	\?\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\	0.51 0.35 0.35 0.54 8.16 9.29 8.31 8.77 53.57 40.07 62.75 19.39 54.08 15.11 57.51 58.62 0.05 0.04 0.05 0.11 0.06 0.16 0.04 0.05 0.05 0.11	11.37 10.07 10.21 11.59 27.86 31.18 27.88 31.18 154.83 126.93 26.42 76.48 154.80 54.33 34.43 34.43 34.43 6.97 6.05 8.80 6.45 9.07 6.84 6.05 7.88 7.88 7.88 7.88 7.88 7.88 7.88 7.8
	evDRIFT evDRIFT evDRIFT DRIFT EVDRIFT	$ \begin{array}{l} \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:F,pg\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:T,th:F,pg\rangle \\ \langle tl:1,tp:F,th:F,pg\rangle \\ \langle tl:1,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1$	\?\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\	0.51 0.35 0.35 0.54 8.16 9.29 8.31 8.77 53.57 40.07 62.75 19.39 54.08 15.11 57.51 58.62 0.05 0.04 0.05 0.11 0.04 0.04 0.04 0.04 0.05 0.05	11.37 10.07 10.21 11.59 27.86 31.18 27.88 31.18 154.83 26.42 76.48 154.83 34.43 34.43 34.43 6.95 6.84 6.05 8.80 9.07 6.84 6.05 8.84 8.84 8.84 8.84 8.84 8.84 8.84 8.8
	evDrift evDrift evDrift evDrift Drift evDrift Drift evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift evDrift	$ \begin{array}{l} \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,oct\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:T,th:F,pg\rangle \\ \langle tl:0,tp:F,th:T,st\rangle \\ \langle tl:1,tp:T,th:F,pg\rangle \\ \langle tl:1,tp:T,th:F,pg\rangle \\ \langle tl:1,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:F,th:T,ls\rangle \\ \langle tl:1,tp:F,th:T,st\rangle \\ \langle tl:1,tp:T,th:F,th:T,st\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1,tp:T,th:T,st\rangle \\ \langle tl:1$	\?\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\	0.51 0.35 0.35 0.54 8.16 9.29 8.31 8.77 53.57 40.07 62.75 19.39 54.08 15.11 57.51 58.62 0.05 0.04 0.05 0.11 0.06 0.16 0.04 0.05 0.05 0.11	11.37 10.07 10.21 11.59 27.86 31.18 27.88 31.18 154.83 126.93 26.42 76.48 154.80 54.33 34.43 34.43 34.43 6.97 6.05 8.80 6.45 9.07 6.84 6.05 7.88 7.88 7.88 7.88 7.88 7.88 7.88 7.8

	Drift	$\langle tl:1, tp:T, th:T, oct \rangle$?	11.44	48.35
	DRIFT	$\langle tl:1, tp:F, th:F, pg \rangle$	Ż	33.15	25.93
	DRIFT	$\langle tl:1, tp:T, th:F, pg \rangle$	1	37.84	28.25
			?		
	DRIFT	$\langle tl:0, tp:F, th:T, ls \rangle$	٠ •	3.25	24.13
	Drift	$\langle tl:1, tp:F, th:T, ls \rangle$?	6.18	21.97
	Drift	$\langle tl:1, tp:T, th:T, st \rangle$?	8.46	25.60
	Drift	$\langle tl:1, tp:T, th:T, ls \rangle$?	7.41	22.17
	Drift	$\langle tl:1, tp:F, th:T, st \rangle$?	6.75	25.72
	<pre>evDrift</pre>	$\langle tl:1, tp:F, th:T, ls \rangle$? ? ? ?	0.46	10.33
	ev Drift	$\langle tl:1, tp:T, th:T, st \rangle$?	0.63	12.52
	ev Drift		~	1.32	11.56
	evDrift		?	0.14	9.46
	evDrift		?	0.41	10.03
	evDrift		?	0.52	10.29
	evDrift		? ? ?	0.12	8.41
	evDrift		ż	1.20	11.18
	evDrift		?	0.47	10.17
	evDRIFT	$\langle tl:1, tp:F, th:T, st \rangle$?	0.56	12.44
	evDRIFT		Ż	0.36	10.51
	evDRIFT		?	0.46	8.02
21. temperature	evDRIFI	$\langle ii:0,ip:F,in:I,oci\rangle$		0.11	0.02
21. temperature	Drift	$\langle tl:0, tp:F, th:T, ls \rangle$	M	70.47	1000.00
	_				
	DRIFT	$\langle tl:1, tp:T, th:F, pg \rangle$	T	930.81	177.64
	Drift	$\langle tl:1, tp:F, th:F, pg \rangle$	T	900.24	
	Drift	$\langle tl:1, tp:F, th:T, oct \rangle$?	287.57	
	Drift	$\langle tl:0, tp:F, th:T, oct \rangle$?	330.16	471.22
	Drift	$\langle tl:0, tp:F, th:F, pg \rangle$?	785.20	
	Drift	$\langle tl:0, tp:F, th:T, st \rangle$	M		1000.00
	Drift	$\langle tl:1, tp:T, th:T, oct \rangle$	T	930.92	1000.00
	Drift	$\langle tl:1, tp:T, th:T, ls \rangle$	T	900.25	294.32
	Drift	$\langle tl:1, tp:F, th:T, st \rangle$	M	717.22	1000.00
	Drift	$\langle tl:1, tp:F, th:T, ls \rangle$	T	930.92	309.12
	Drift	$\langle tl:1, tp:T, th:T, st \rangle$	T	930.90	209.29
	evDrift	$\langle tl:0,tp:F,th:T,st\rangle$?	13.11	71.29
	evDrift		?	9.22	91.67
	evDrift	\ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \	Ż	46.16	30.32
	evDrift		?	17.10	49.12
	evDrift	$\langle tl:1, tp:F, th:T, ls \rangle$	•	8.74	45.16
	evDrift		•	9.75	97.21
	evDRIFT evDRIFT		•	40.52	27.56
	evDRIFT		? ? ? ? ? ?	11.38	59.50
	evDRIFT		•	14.67	41.66
	evDRIFT evDRIFT		•	9.97	54.15
		$\langle tl:1, tp:F, th:T, st \rangle$?		
	evDrift		· /	17.75	88.90
	ev Drift	$\langle tl:1, tp:F, th:F, pg \rangle$	V	35.27	26.09
	•				

