Xipho: Extending Tropos to Engineer Context-Aware Personal Agents

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ABSTRACT

We introduce Xipho, an agent-oriented methodology for engineering context-aware personal agents (CPAs). Xipho extends Tropos to support CPA development. Xipho’s steps span a CPA’s requirements acquisition, design, and implementation. Importantly, we treat context as a cognitive notion and systematically relate it to other cognitive notions such as goals and plans. Xipho incorporates reusable components in a CPA’s design and implementation to simplify the development process. We evaluate Xipho empirically, finding that Xipho reduces development time and effort, and improves the comprehensibility of CPA designs.

Categories and Subject Descriptors

D.2.1 [Software Engineering]: Requirements and Specifications—Methodologies

General Terms
Design, Experimentation, Human Factors

Keywords
Methodology, Context, Personal agent, Tropos

1. INTRODUCTION

Humans have an inherent understanding of the contexts in which they act and interact. A context-aware personal agent (CPA) adapts to the contexts of its human user. CPAs can prove valuable in settings such as healthcare, smart (physical or virtual) environments, and e-commerce.

Engineering a CPA is nontrivial. First, a CPA must capture its users’ mental models of context— a high-level concern centered on meaning. Second, a CPA must acquire the desired contextual information—a low-level concern centered on devices and infrastructure. We describe Xipho, a methodology for systematically developing a CPA.

We treat context as a cognitive notion and understand other cognitive notions, such as goals and plans, as inherently related to context. Thus, a natural approach to developing a CPA would be an agent-oriented software engineering (AOSE) methodology that employs cognitive notions throughout development. Existing AOSE methodologies, e.g., [6, 17, 22], describe generic steps of software development, but fall short in dealing with challenges specific to CPA development. Xipho fills this gap by providing systematic steps for (i) capturing a CPA’s contextual requirements, (ii) deriving a context information model specific to a CPA, and (iii) leveraging reusable components in a CPA’s design and implementation. These tasks pose nontrivial challenges (described below). We demonstrate that Xipho addresses the challenges of CPA development successfully.

A CPA’s contextual requirements are often (i) unknown ahead of time, and (ii) subject to change as users employ the CPA in different contexts. A developer, inevitably, makes assumptions about a CPA’s users’ contextual needs, but often buries such assumptions in the implementation. Xipho provides constructs necessary to explicate such assumptions, yielding easily renewable CPAs [20].

Context is traditionally defined as “any information relevant to an interaction between a user and an application” [8]. Accordingly, the space of what constitutes context is vast, e.g., a user’s location, activities, emotions, or social setting. Existing techniques [4] model context as a notion generic across applications and users, which a developer must tailor to the requirements of a CPA. Xipho assists a developer in restricting a CPA’s context information model to a set of abstractions meaningful in the CPA’s scope, enabling the CPA to offer a natural user experience.

To acquire the desired context information, a CPA must address device and network centric concerns such as sensing, aggregating, and propagating context information. However, the concerns of context acquisition can be separated from those of CPA development. Importantly, several existing works address the problem of context acquisition [2]. Xipho enables a developer to build a CPA on reusable components, reducing the cognitive burden of CPA development and yielding easily comprehensible CPA designs.

Contributions. Our contributions are two fold. First, we propose Xipho as an extension of Tropos for developing CPAs. Xipho addresses nontrivial challenges associated with requirements acquisition, design, and implementation of a CPA. We demonstrate Xipho via a case study, which involves the engineering of a smart phone based CPA.

Second, we evaluate Xipho through a study in which 46 developers applied Xipho to engineer three CPAs. Its results support our claims that Xipho (i) reduces the time and effort required to develop a CPA, and (ii) yields CPA designs that are easy for other developers to comprehend.

2. BACKGROUND: TROPOS
Xipho extends Tropos [6] to support CPA development. Specifically, Xipho adopts the Tropos metamodel, which consists of the following main constructs.

**Actor:** A social, physical, or software agent (or a role of an agent). An actor has goals within a system.

**Goal:** A strategic interest of an actor. A hard goal has a crisp satisfactory condition. A soft goal has no clear-cut definition or criterion for deciding whether it is satisfied or not. Thus hard goals are satisfied whereas soft goals are satisfied.

**Plan:** An abstraction of doing something. Executing a plan is a means of satisfying or satisfying a goal.

**Resource:** A physical or information entity.

**Dependency:** A relationship indicating that a depender actor depends on a dependee actor to accomplish a goal, execute a plan, or furnish a resource. The object (goal, plan, or resource) here is the dependum.

**Belief:** An actor’s representation of the world.

**Capability:** An actor’s ability to choose and execute a plan to fulfill a goal, given certain beliefs and resources.

Our motivation to extend Tropos is that it spans all development phases. First, Tropos captures early and late requirements as system-as-is and system-to-be models, respectively. A system-as-is model captures (i) the actors involved: primary users of the application as well as those indirectly affected by it, (ii) goals and plans of each actor, and (iii) dependencies among actors on their goals or plans. A system-to-be model introduces the solution as the system-to-be actor and its goals, plans, and dependencies. In the following phases, Tropos maps the system-to-be actor into one or more agents, and derives a detailed specification of agents’ capabilities to implement on a chosen platform.

3. XIPHO
Xipho augments Tropos with tasks specific to CPA development in each development phase as shown in Table 1. Before describing Xipho’s steps, we introduce a case study, and derive its system-as-is and system-to-be models.

**Case Study: Ringer Manager**
We demonstrate Xipho via a case study, which involves engineering the Ringer Manager Application (RMA), a CPA for phones to help a user better handle incoming calls.

**Automated ringer mode.** The RMA sets an appropriate ringer mode on the user’s phone based on the user’s context at the time of an incoming call. The alternatives (assumed to be mutually exclusive) are to set the ringer mode to silent, vibrate, or loud.

**Automated notification.** If the user does not answer the call, the RMA sends a notification to the caller. The notification can be generic (e.g., “leave your name and number”), or describe the user’s context at the time of missing the call, either abstractly (e.g., “in a meeting”) or in detail (e.g., “in a meeting with Bob at the Starbucks”).

We imagine the system-as-is as follows. Each episode starts when a caller tries to reach a callee by phone. The callee wants to be reachable unless he wants to work uninterrupted. The callee’s plan is to answer the call if he wants to be reachable and not answer otherwise. The callee’s decision to answer or not answer depends on (i) whether he disturbs a neighbor by answering or (ii) if the caller has a pressing need to reach him. In these cases, the callee depends on the neighbor or the caller to provide appropriate information. The callee sets an appropriate ringer mode on his phone to help him answer or not (e.g., loud to answer, silent to not). Next, when the callee does not answer a call, he would notify the caller of a reason (e.g., busy, in a class, talking to boss, and so on) or to ignore the call depending on who the caller is. If he decides to notify the caller, he would disclose only the necessary details, preserving privacy.

![Figure 1: Actor model: Callee’s perspective.](image)

![Figure 2: Expanding the RMA’s perspective.](image)
3.1 Step 1: Context-Means Analysis

A CPA needs to make decisions based on the contexts of one or more of the actors involved. The objective of context-means analysis is to identify scenarios where an actor’s context provides the application a means of making a decision. We describe four types of such scenarios with examples.

**OR-decomposition**, where some decomposed goals or plans are to be chosen over the rest based on context, e.g., whether to set the ringer mode as silent or vibrate—vibrate may be acceptable in a seminar, but not in a one-on-one meeting.

**Conflicting goals**, where the goal chosen for accomplishment depends on context. For example, the RMA must choose between the callee’s goals to be reachable and to work uninterrupted. This decision could be based on the callee’s context—busy or not.

**Soft goal**, where the extent to which the goal is satisfied depends on context. For example, each ringer mode satisfies the soft goal to not disturb a neighbor differently. The chosen ringer mode could be based on who the neighbor is, e.g., set as silent near a colleague, vibrate near a family member, and loud near a stranger.

**Dependency**, where the dependum can be refined based on context. For example, the dependum to be reachable can be refined to context because the actual dependency is that the callee depends on the caller to provide contextual information (e.g., caller’s context indicating whether he has a pressing need to reach the callee).

A developer must identify all scenarios of each type described above and perform one of the following for each:

- If the scenario is influenced by the primary user’s (callee) context, capture the influence as a belief and add context-means links from the belief to each goal or plan involved in the scenario.
- If the scenario is influenced by a secondary user’s (caller or neighbor) context, capture the context as a resource and add (or update) a dependency with the context resource as the dependum. Also, add context-means links from the resource to each goal or plan involved in the scenario.

The motivation is that the CPA would maintain beliefs about its primary user, and access information resources about the secondary users as shown in Figure 3.

3.2 Step 2: Context Information Modeling

We used a context abstraction as a placeholder for each contextual belief or resource in the previous step. Now, we systematically refine these abstractions in the CPA’s scope for two reasons: (i) a motivation for model-driven development is to document the developer’s thought process by explicitly capturing his or her intuitions, and (ii) a detailed model would yield a detailed specification, potentially making the implementation easier. To derive a CPA’s context information model, identify:

**A context model** for each generic abstraction found in the previous step such that the context model consists of cognitive abstractions sufficient to make the decision specific to the context-based scenario influenced by the corresponding generic abstraction. For example, in Figure 3, Context abstraction 2 is used to decide whether to set the ringer mode as loud or vibrate. This generic abstraction can be modeled as a spatial abstraction, Ambience, assuming that all that matters in setting the ringer mode as loud or vibrate is the callee’s ambience. The decision to not set as silent must already have been made, using Context abstraction 3.

**Context instances** of a context abstraction, where appropriate, such that a context instance represents all situations, within the scope of the corresponding abstraction,
that lead to the same context-based decision. For example, context instances of Ambience could be Noisy and Quiet assuming that the ringer mode would be vibrate if the ambience is Quiet and loud if Noisy. However, to gain adaptivity, it would be desirable to elicit the instances of an abstraction at run time. We refer to such an abstraction as an open abstraction. For example, modeling the callee’s activity as an open abstraction helps us elicit from the user which of his activities are to be uninterrupted.

Figure 4 shows a context information model derived for the RMA (each context instance is highlighted with a thick border). We restrict the case study to the ringer management aspect of the RMA (omitting notifications) for simplicity. We employed the context abstractions of space, activity, and social circle described in an existing metamodel [16], which however is loosely coupled with Xipho.

3.3 Step 3: Context Middleware

Once we derive a CPA-specific context information model, how can we enable the CPA to acquire this information? To acquire context information, the CPA must: Elicit context instances of each open context abstraction from the primary user, e.g., elicit from the callee that the desired instances of the Social circle abstraction are Family, Colleagues, and Others. Recognize context instances of each context abstraction from sensors, e.g., recognize the callee’s Ambience as Quiet via data from the microphone on the callee’s phone. Acquire context resources from the secondary users, e.g., acquire from the caller that the Caller’s context is Casual. These are nontrivial tasks, but common to all CPAs. Although we model context information specific to each CPA, the abstractions can overlap as a user employs multiple CPAs (especially, since the abstractions are high-level, cognitive constructs). Thus, Xipho incorporates a middleware architecture in which (i) a reusable middleware agent elicits and recognizes a user’s contexts, and (ii) multiple CPAs interact with the middleware to acquire desired contexts.

Figure 5 shows the middleware actor in the RMA’s architecture. Importantly, such middleware components have been realized, e.g., [2, 14, 16]. Xipho can incorporate any architecture in which (i) a reusable middleware agent elicits and construct. Thus, Xipho incorporates a middleware architecture in which (i) a reusable middleware agent elicits and recognizes a user’s contexts, and (ii) multiple CPAs interact with the middleware to acquire desired contexts.

Figure 5 shows the middleware actor in the RMA’s architecture. Importantly, such middleware components have been realized, e.g., [2, 14, 16]. Xipho can incorporate any architecture in which (i) a reusable middleware agent elicits and recognizes a user’s contexts, and (ii) multiple CPAs interact with the middleware to acquire desired contexts.

3.4 Step 4: Contextual Capability Modeling

The objective of this step is to obtain a detailed agent specification to simplify the implementation. Xipho’s specification of a CPA is a set of contextual capabilities, each conditioned on a context abstraction at an instance. A contextual capability can be represented as a rule, e.g., Ambience = Noisy → Set as loud. A developer performs the following substeps to derive an application specification:

- Identify agent capabilities, e.g., choosing and executing a plan, choosing a goal to accomplish, and managing a dependency.
- Identify the context abstraction that conditions each capability, replacing the generic context abstraction placeholders of Step 1 with specific abstractions from Step 2.

Figure 6 shows a refined actor model of the RMA that combines context abstractions and (highlighted) capabilities. This model can be used to generate a detailed set of contextual capabilities. Table 2 lists the contextual capabilities we identified for the RMA. We use variables (τA1, τS1, etc.) to capture instances of open abstractions.

3.5 Step 5: Implementation

Now, a developer must implement techniques to Interact with the middleware to determine (i) elicited instances of open abstractions, e.g., to determine that instances of Activity are Working, Driving, and Dining, and (ii) the instance at which an abstraction is at a given time, e.g., to determine if Activity = Working, now. Substitute variables in a contextual capability with in-
Exercise capabilities by executing the rules derived in the previous section, e.g., exercise Activity = Working → Set as silent ∨ Set as vibrate.

4. COMPARISON

Xipho is an AOSE methodology tailored specifically for CPA development. However, what are the benefits of Xipho? To answer this, we compare the Xipho’s RMA model shown in Figure 6 with an alternative model shown in Figure 7.

The alternative model enhances goals and plans in Figure 2 to incorporate context. The alternative model represents three major mistakes a developer, not applying Xipho, can commit. The alternative model:

Lacks explicit semantics of context, whereas Xipho models convey the semantics described in Steps 1 and 2. Such lack leads to ambiguity in interpreting a model. For example, Figure 7 is not clear about whether two goals (e.g., . . . if not working . . . and . . . if at office . . . ) conflict; similarly, the figure does not convey that the ringer mode must be silent only if the call is not urgent and the callee’s ambience is quiet.

Introduces redundancy in the context information model, whereas Xipho removes it by incorporating cognitive constructs. For example, each goal in Figure 7 describes a contextual condition involving activities, redundantly. In contrast, Figure 6 simplifies the model by including the Activity open abstraction.

Does not separate the concerns of context acquisition from the RMA design, whereas Xipho cleanly separates the RMA’s and middleware’s concerns. For example, Figure 7 describes noise levels used to decide a ringer mode within RMA’s design. In contrast, Figure 6 delegates such tasks to the middleware, simplifying the RMA’s design.

5. EMPIRICAL EVALUATION

The foregoing intuitions lead us to hypothesize that Xipho (i) reduces the time and effort required to develop a CPA, and (ii) enhances the comprehensibility of CPA designs (for other developers). We evaluated our hypotheses in a developer study, comparing Xipho against the baseline of Tropos.

5.1 Study Design

Our subjects were 46 students of a graduate level computer science course. Each subject worked in a team of three (12 teams), two (three teams), or one (four subjects) of his or her choosing. Subjects received a partial grade toward course credit for producing all deliverables. The study was approved by the Institutional Review Board (IRB) and we obtained an informed consent from each subject. Nonparticipants could work on an alternative task.

We conducted the developer study in three phases. Practice, which required each team to learn one of Tropos or Xipho, and exercise it to model an application, which we reviewed to help them understand.

Modeling, which required each team to model a second application. No feedback was given during this phase.

Verification, which required each subject (working solo) to verify an existing model of a third application for completeness and comprehensibility.

The study lasted for eight weeks—two weeks per phase for subjects and a week each between phases for us to review.

5.1.1 Study Units

Subjects completed a prestudy survey about their experience in software modeling and development (of context-aware and mobile applications, and in general). Using this information, we formed three groups of teams such that teams’ skill sets and sizes balanced across groups.

In the first phase, we assigned one of the following applications to each group. In the subsequent phases, we rotated the assignments as shown in Table 3. For each application, we provided the following description and three–four scenarios to each group. In the subsequent phases, we rotated the assignments as shown in Table 3. For each application, we provided the following description and three–four scenarios to each group.

Table 2: RMA specification.

<table>
<thead>
<tr>
<th>ID</th>
<th>Contextual Condition</th>
<th>→ Capability</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_1$</td>
<td>Activity = $A_1$ ∧ Social circle = → Set as loud ∨ $S_1$ ∧ Neighbor’s context = $?$ &amp; Caller’s context = Casual</td>
<td></td>
</tr>
<tr>
<td>$C_2$</td>
<td>Activity = $A_2$ ∧ Social circle = → Set as silent ∨ $S_2$ ∧ Neighbor’s context = $?$</td>
<td>Set as vibrate</td>
</tr>
<tr>
<td>$C_3$</td>
<td>$C_1$ ∧ Ambience = Quiet</td>
<td>→ Set as vibrate</td>
</tr>
<tr>
<td>$C_4$</td>
<td>$C_1$ ∧ Ambience = Noisy</td>
<td>→ Set as loud</td>
</tr>
<tr>
<td>$C_5$</td>
<td>$C_2$ ∧ Ambience = Quiet</td>
<td>→ Set as silent</td>
</tr>
<tr>
<td>$C_6$</td>
<td>$C_2$ ∧ Ambience = Noisy</td>
<td>→ Set as vibrate</td>
</tr>
</tbody>
</table>

![Figure 7: A model derived without Xipho.](image)
Table 3: Application assignments in each phase.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Task</th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Practice</td>
<td>Alarm</td>
<td>Motivator</td>
<td>Reminder</td>
</tr>
<tr>
<td>2</td>
<td>Modeling</td>
<td>Motivator</td>
<td>Reminder</td>
<td>Alarm</td>
</tr>
<tr>
<td>3</td>
<td>Verification</td>
<td>Reminder</td>
<td>Alarm</td>
<td>Motivator</td>
</tr>
</tbody>
</table>

5.1.2 Alternatives

Teams within each group (1, 2, or 3) were divided into two groups (again, with balanced skill sets and team sizes).

Control group (C): provided with the modeling primitives, a description, and example models from Tropos.

Xipho group (X): provided with the steps, modeling primitives, and the RMA example.

5.1.3 Deliverables

In each of the first and second phases, subjects were given an application specification (and a methodology) and asked to deliver (i) a model of the application (covering all specified scenarios); (ii) responses to a survey after each work-session recording the time spent (in hours and minutes), and effort expended (on a scale of 1~easy to 7~difficult) during the session. The survey also required subjects to record a detailed breakdown of tasks they performed in each session.

In the third phase, each subject was given the specification of a third application and two models of it produced by other subjects (one from Control and one from Xipho team) in the second phase. A description of the Xipho’s primitives was provided to those who did not apply Xipho in earlier phases. Our motivation was to compare the comprehensibility of models by subjects experienced with Xipho and those new to it. The subjects were asked to verify the model and answer a survey to record (i) a rating of how complete the model was (on a scale of 1~incomplete to 7~complete), and (ii) a rating of how comprehensible a model was (on a scale of 1~easy to 7~difficult) relative to each context-based application scenario the model handled.

We allowed teamwork in the first two phases, but required solo work in the third because (i) such ratings are inherently subjective, and (ii) the third phase was less demanding than the first two, and we expected subjects to complete the deliverables (in time) without compromising quality.

5.2 Results

We performed two-tailed (i) $t$-test to compare the difference in mean ($\mu$) time spent, (ii) $F$-test to compare the difference in the variances ($\sigma^2$) of time spent, and (iii) Wilcoxon’s ranksum-test to compare the difference in the median ($\tilde{x}$) of effort ratings during Practice and Modeling [12]. We compared medians for the effort ratings since rating is ordinal.

With respect to the Practice and Modeling phases, Figure 8 shows box plots of times spent, and Figure 9 shows effort perceived, building models (there were no instances of the lowest rating). The figures also show the result of hypothesis testing (“*” and “**” indicate sufficient evidence to reject the corresponding null hypothesis at significance levels of 10% and 5%, respectively).

Recall that each model produced in Modeling was rated by more than one subject for completeness and comprehensibility during Verification. First, we measured the interrater reliability for ratings of each model using Krippendorff’s al-

5.3 Discussion

5.3.1 Time and Effort of Model Building

We found that the time and effort expended by a Xipho team in the Modeling phase are significantly lower than those expended by a Control team ($p = 0.046$ and $p = 0.01$, respectively). This validates that Xipho, a methodology tailored for CPA development, can simplify the development process as opposed to a generic methodology.

Next, we found that the differences in time spent and effort were not significantly different during the Practice phase (when teams were learning Xipho or Tropos). However, we made an important observation—the variance in time spent was significantly larger for Control than Xipho teams, although Control teams had fewer primitives to learn than Xipho teams. We speculate that such difficulties could lead a developer, especially a beginner, to give up modeling. Thus, a methodology with systematic steps specific to CPAs is essential for the success of model-driven development of CPAs.
A wealth of context-aware systems research [2] focuses on providing architectural support for developing context-aware applications, usually via a middleware, e.g., [11, 14, 16, 19], to protect developers from low-level concerns of context acquisition. Often, such architectures provide a generic context metamodel [4], which an application developer must tailor during development. Sollenberger and Singh [21] show that developers employing a systematic methodology benefit more from a middleware than those who do not. CPA developers can employ Xipho with any middleware that can elicit and reason about context instances. Bolchini et al. [5] describe a context-aware system that centrally manages contextual data. In contrast, Xipho’s middleware agent manages a user’s contextual data locally and advocates users to interact for satisfying dependencies on contextual resources.

### AOSE Methodologies

AOSE promotes development activities to capture high-level abstractions, e.g., agents and goals over low-level abstractions, e.g., classes and methods. Xipho extends Tropos to explicitly deal with the cognitive notion of context.

Ali et al. [1] capture context-based scenarios as variation points and employ them to analyze requirements. Whereas their focus is to analyze a contextual goal model to detect conflicts and inconsistencies among requirements, Xipho deals with context in requirements as well as in design and implementation. Zacarias et al. [23] describe a context-aware agent-oriented ontology for modeling human agents in an enterprise setting. Whereas they provide a metamodel (ontology) to describe the dynamic and situated human behavior, Xipho provides systematic steps to exploit such a metamodel for developing CPAs.

Xipho’s context analysis, modeling, and specification steps are generic, and can be employed in other AOSE methodologies. Prometheus [22] can be extended to incorporate context as percepts and external data used to describe the environment. Xipho can be incorporated into ADELFE [3] to characterize the environment, where ADELFE’s active and passive entities correspond to Xipho’s context instances and open abstractions. Rahwan et al. [17] describe a social modeling extension to the ROADMAP methodology. Xipho brings together a social model, users’ activities, and spatial attributes into a context model, which can be linked a role’s responsibilities, generalizing Rahwan et al.’s extension.

### Other Methodologies

Ceri et al. [7] employ WebML to model context and context-triggered adaptive actions in a user-independent manner. Serral et al. [18] employ a domain-specific PervML to model context followed by auto generation of code that represents and handles context. Henricksen and Indulska [10] employ
CML (Context Modeling Language) to model context and preference modeling to rank context-based choices of a user. These methodologies describe how to model context, assuming that a developer knows what aspects of context to model and why. Xipho helps a developer not only to model context, but also to arrive at meaningful context abstractions and instances specific to an application scenario.

7. CONCLUSIONS AND DIRECTIONS

This paper has shown how an agent-oriented methodology can be enhanced to engineer CPAs, an important problem that has not been adequately addressed in the literature. Our findings about the benefits of Xipho bear important implications for its practical adoption. A huge market for CPAs already exists in the form of smart phone applications (such as RMA). Further, we conjecture that applications produced using Xipho offer a more natural user experience than those built conventionally. We are considering ways to design a tractable study to evaluate this claim.

Xipho provides a key component of our overall vision of developing CPAs. On the one hand, Xipho extends the benefits of a goal-based methodology (specifically, Tropos) to CPAs—context is arguably naturally understood via cognitive notions. On the other hand, Xipho builds a CPA on a reusable middleware, separating the concerns of context acquisition from CPA development. Our implementation of the middleware elicits a user’s context instances and learns to recognize them from sporadic sensor data via semi-supervised machine learning. Our ongoing work seeks to reduce user effort in context elicitation via active learning.

Systematically contextualizing cognitive notions such as privacy and trust is largely unexplored. A contextual approach to privacy and trust could facilitate applications with multiple interacting CPAs. Such an extension could build on existing approaches for finding social relationships between agents sharing a context and coordinating agents by transparently propagating the context information.

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8. REFERENCES