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## 4TH INTERNATIONAL CONFERENCE ON

# PUBLIC KEY INFRASTRUCTURE AND ITS APPLICATIONS (PKIA 2023)

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## Scalable Model-Based Decentralized Applications in the Cloud Using Certificates and Blockchains

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# Scalable Cloud Applications

- ***State-of-the-art***
  - *Auto scaling of virtual machines (e.g. EC2 Autoscaling, Azure Scale Sets etc.)*
  - *Lambda functions (e.g. AWS Lambda)*
  - *Serverless computing independent of virtual machines (e.g. AWS Step Functions)*
- ***Result***
  - *Vertical and horizontal scaling*
  - *Distribution across servers and data center regions*
  - *Ideally: distribution, high performance, scalability, availability*

# Decentralization

***Challenges***

- *Partially conflicting goals (CAP theorem)*
- *Centralized architectures of cloud providers*
  - *Dependency on individual providers*
  - *Dependency on centralized technical infrastructures*
- *Centralized coordination of application executions*
  - *Limitations when executing applications in distributed or federated scenarios*
  - *Distributed parties cannot observe and verify application executions*

→ ***Distribution does not imply decentralization***

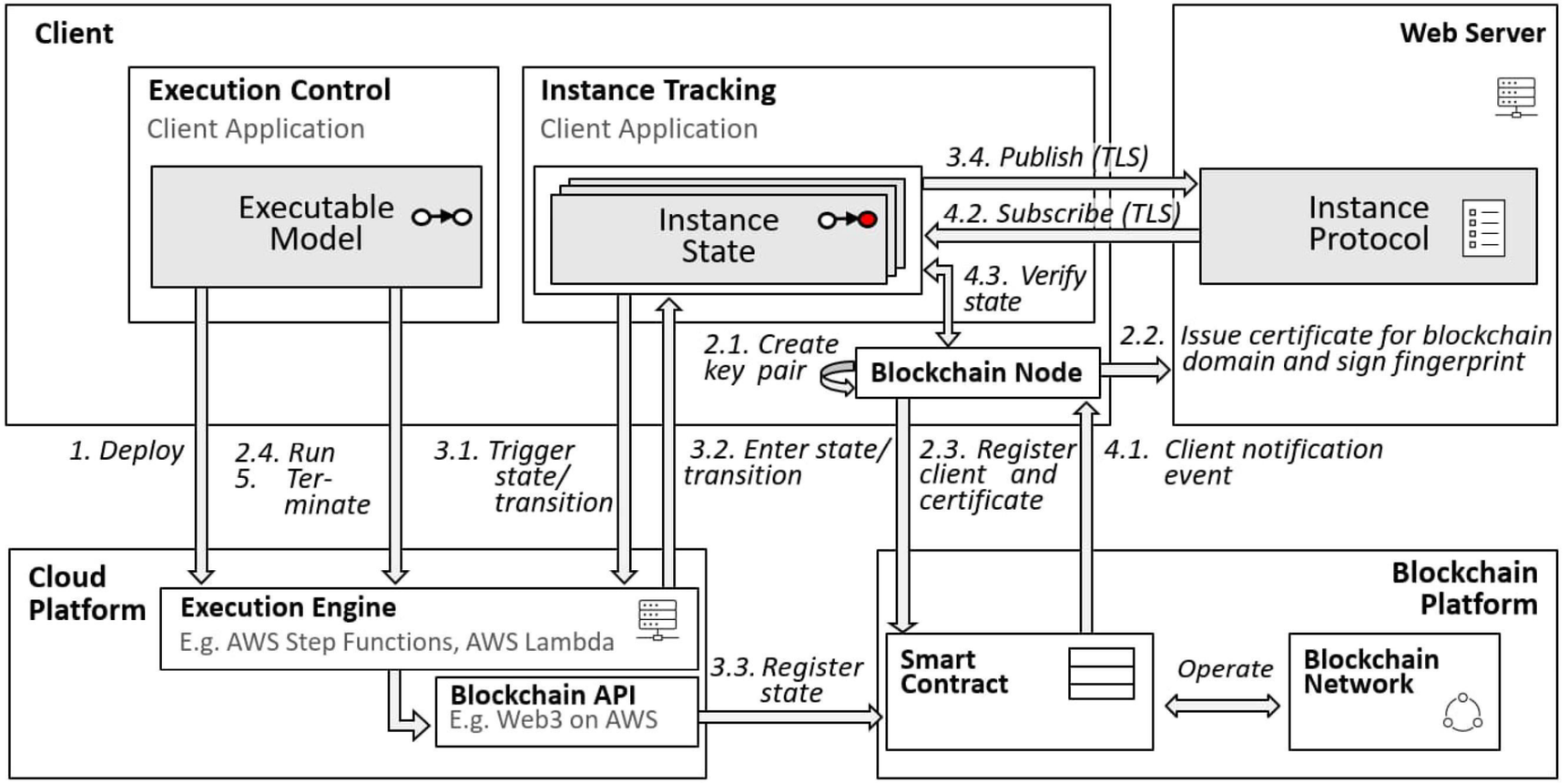
→ ***Decentralization: distribution and non-centralized coordination***

# Architectures for Decentralized Applications

- *Blockchain*
  - *Execution of application logic in smart contracts, verifiable execution*
  - *Problems: insufficient scalability, websites and applications outside the blockchain out of scope*
- *Combination of cloud platforms and blockchains*
  - *Execution of applications on cloud platforms with instance tracking on a blockchain*
  - *Prior Work:* Härer(2022): Executable Models and Instance Tracking for Decentralized Applications - Towards an Architecture Based on Blockchains and Cloud Platforms

***Research Objective: Extension of a decentralized application architecture for authenticated and scalable distribution, execution, and tracking.***

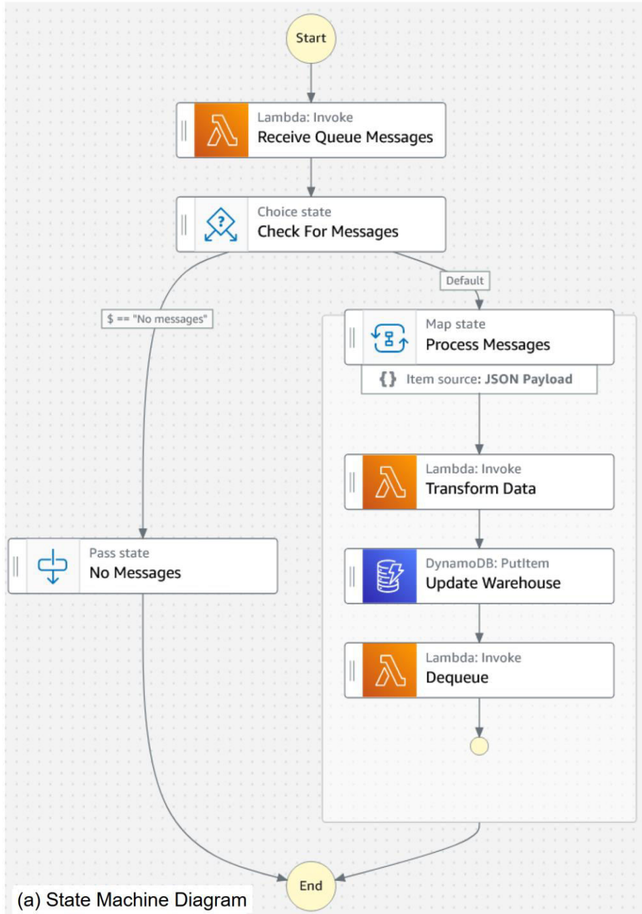
# System Architecture



# Model-based Specification

*1. Deploy*

- *Deployment of executable model with content-based identifier*
  *m = (model_id, model_data)*
  *model_id = H(model_data)*
- *Platform-specific model data*
- *Example: State machine representation for AWS Step Functions using JSON data*




```
{
  "StartAt": "Receive Queue Messages",
  "States": {
    "Receive Queue Messages": {
      "Type": "Task",
      "Resource": "arn:aws:states:::lambda:invoke",
      "OutputPath": "$.Payload",
      "Parameters": {
        "FunctionName": "arn:aws:lambda:us-east-1:72621(
      },
      "Next": "Check For Messages"
    },
    "Check For Messages": {
      "Type": "choice",
      "Choices": [
        {
          "Variable": "$",
          "StringEquals": "No messages",
          "Next": "No Messages"
        }
      ],
      "Default": "Process Messages"
    },
    "No Messages": {
      "Type": "Pass",
      "End": true
    },
    "Process Messages": {
      "Type": "Map",
      "ItemsPath": "$",
      "Parameters": {
        "MessageNumber.$": "$$.Map.Item.Index",
        "MessageDetails.$": "$$.Map.Item.Value"
      },
      "Iterator": {
        "StartAt": "Transform Data",
        "States": {
          "Transform Data": {
            "Type": "Task",
            "Resource": "arn:aws:states:::lambda:invoke",
            "OutputPath": "$.Payload",
            "Parameters": {
              "Payload.$": "$",
```

(b) JSON

h = c632cb64251cfdb18cb6dcab680b9fc82952aea783538ed246a4cb84f65b81e1

# Setup: Keys, Certificate and Blockchain Domain

*2.1 Key Pair*

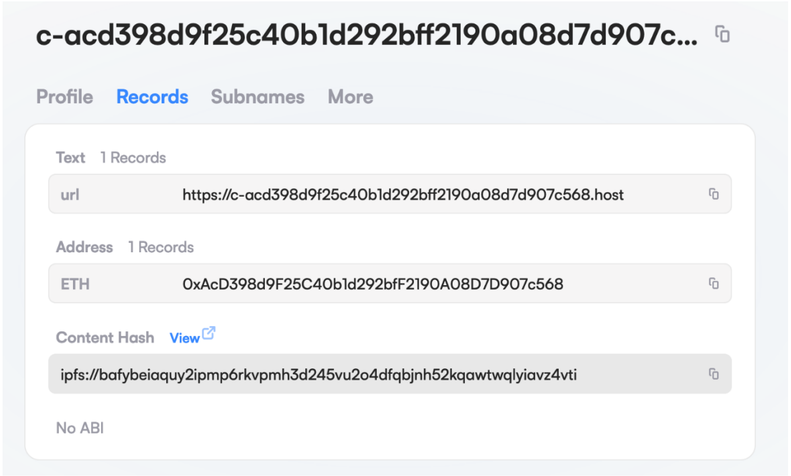
- *Local generation of (k_pub, k_prv) and blockchain address, here: Ethereum w/ ECDSA, scp256k1*

*2.2 Certificate and Blockchain Domain*

- *Web server for distribution of model, instance protocol with X.509 certificate*
- *Blockchain domain records linking address, domain, uri*
  - *Here: Ethereum Name Service (ENS)*
  - *Resolves: bc.-address → uri and uri →* bc.-address

*2.3 Register client certificate*

- *Smart contract for registering addresses with certificates*
- *Certificate is signed with k_prv and stored by fingerprint in the contract*



# Instance States

*3.1 Trigger state / transition*

- *Cloud platform or client triggers state change*

*3.2 Enter state / transition*

- *Execution engine changes state*
- *Captures state with content-based identifier and triggers event*

*3.3 Register state*

- *Records in smart contract*

*3.4 Publish*

- *Updates instance protocol via TLS*

| | event_ | state_hash | time | block_ | client_address | transaction_hash |
|---|---|---|---|---|---|---|
| 1 | Register State | 2f5017eb565ae673b27f22e43ecd4fe8e71dce1b18f887fac725403205bc0e25 | 1678443257 | 3,060,324 | AcD398d9F25C40b1d292bfF2190A08D7D907c568 | e21489fa54c832f95275e |
| 2 | Register State | 54dc36f33bbedce87d29a2862436de6084e9fccc6354645949818f94ec48d6d6 | 1678443268 | 3,060,325 | AcD398d9F25C40b1d292bfF2190A08D7D907c568 | 1c2bc34e9ee4d0724130 |
| 3 | Register State | d4630c072363adfcc080209eb21b4f53eed94bb136a14598b9e8fd6c62a488ff | 1678443278 | 3,060,326 | AcD398d9F25C40b1d292bfF2190A08D7D907c568 | 65a131ec6e0292147c55 |
| 4 | Register State | cdec2cb2a3ab16c8802e27d9eb03d9176945b56758e7dea1a14fa3c6024906f3 | 1678443299 | 3,060,327 | AcD398d9F25C40b1d292bfF2190A08D7D907c568 | 5b89790aa2be2d226a3d |
| 5 | Register State | d2baee1c5d7454af61c8511ae1ed2ec5c3a1c3d6e013c14a2be97cf758621cb8 | 1678443310 | 3,060,328 | AcD398d9F25C40b1d292bfF2190A08D7D907c568 | 1d89e0c91b8c4a634659 |
| 6 | Register State | 084350dbf128e5477cddfe2c2b08f8b1475542b8f24f2b0a743222c6018a2826 | 1678443320 | 3,060,329 | AcD398d9F25C40b1d292bfF2190A08D7D907c568 | e50f93ef2250912d77445 |
| 7 | Register State | c959ce88840609f42a6b47512e8c34899bab7947fc9e15b8482d5529aa318e97 | 1678443331 | 3,060,330 | AcD398d9F25C40b1d292bfF2190A08D7D907c568 | a78eb682b6c8d4985e2d |
| 8 | Register State | 192f9904ea2a961f9cb88784a27390aa1fdea5c0b12e89d17bbffd26c06c6d5e | 1678443342 | 3,060,331 | AcD398d9F25C40b1d292bfF2190A08D7D907c568 | ee4fe65d48c1cefc6853c |
| 9 | Register State | 6aeafcd9da42a3de40a2ebc46987b1c4890a0843694396704fb56a33c68e354d | 1678443352 | 3,060,332 | AcD398d9F25C40b1d292bfF2190A08D7D907c568 | 90878ede0db98441e106 |
| 10 | Register State | 21b22a3ba31b4edbf26fdda49c7494659a37a8052a5798f673537f1e540b784c | 1678443363 | 3,060,333 | AcD398d9F25C40b1d292bfF2190A08D7D907c568 | 51049b42463182f012ace |
| 11 | Register State | f09abbd8dedd90de383417cb0edb1c658dea96bd20750e724faa4499f418841f | 1678443373 | 3,060,334 | AcD398d9F25C40b1d292bfF2190A08D7D907c568 | 1b488e7fd311c946468d |
| 12 | Register State | 45ee5c0ce528c078ee18e0697df410758197594771b3eb993e0f76c77b96e9ae | 1678443394 | 3,060,335 | AcD398d9F25C40b1d292bfF2190A08D7D907c568 | e910d4193094c134348c |
| 13 | Register State | 3407328ab665e45f3640965bfd894bf47433d8e7f70ede1e7730edb99279c460 | 1678443405 | 3,060,336 | AcD398d9F25C40b1d292bfF2190A08D7D907c568 | 2c66b9903828a84b8b4ff |

https://c-acd398d9f25c40b1d292bff2190a08d7d907c568.host/a681a01f3b9d2673b7fcf7f622274d55b4634ea313330c3705f631bee2ae779d.json 130%

JSON Raw Data Headers

Save Copy Collapse All Expand All Filter JSON


```
model_hash: "c632cb64251cfdb18cb6dcab680b9fc82952aea783538ed246a4cb84f65b81e1"
instance_hash: "a681a01f3b9d2673b7fcf7f6…3330c3705f631bee2ae779d"
instance_data: "https://c-acd398d9f25c40b1d292bff2190a08d7d907c568.host/data-queue-warehouse-etl-d02ebfb0-4074-436c-9d3f-f9e4e48223fc.json"
model_data: "https://c-acd398d9f25c40b1d292bff2190a08d7d907c568.host/data-queue-warehouse-etl.json"
instance_protocol:
  0:
    event_type: "Register State"
    state_hash: "2f5017eb565ae673b27f22e43ecd4fe8e71dce1b18f887fac725403205bc0e25"
    timestamp: 1678443257
    block_nr: 3060324
    client_address: "acd398d9f25c40b1d292bff2190a08d7d907c568"
    transaction_hash: "e21489fa54c832f95275ef6800be0df71fa43dd2417cf190d3f9a1897428c6df"
    state_data: "https://c-acd398d9f25c40b1d292bff2190a08d7d907c568.host/data-queue-warehouse-etl-d02ebfb0-4074-436c-9d3f-f9e4e48223fc-2.json"
  1:
    event_type: "Register State"
    state_hash: "54dc36f33bbedce87d29a2862436de6084e9fccc6354645949818f94ec48d6d6"
```

# Instance Tracking

*4. Tracking and verifying states*

- *Subscription to state change events and instance protocol over HTTPS/TLS*
- *Validation of states using the smart contract:*
  - *State exists: retrieval and validation of instance state ID / hash value*
  - *Model and instance exist: retrieval and validation of instance and model IDs / hash values*
  - *Blockchain address created model or state: address resolves to known web server uri using ENS*
  - *Instance protocol server certificate known: retrieval of signature from contract*
  - *Instance protocol linked to address: signature check correct for key of blockchain address*

→ *Verifies: each instance state, instance protocol and model with issuer and timestamps*

# Conclusion

***Extended Decentralized Application Architecture***

- *Executable Models on cloud platforms with instance tracking on a blockchain (Härer 2022)*
- *Web- and blockchain authentication*
  - → *Web servers distribute executable models and instances*
  - → *Binding between web resources, certificates and blockchain identities possible*
- *Scalable execution on cloud platforms by an executable model for serverless computing*
  - → *Enhanced scalability for data- and compute intensive applications*
- *Distributed instance tracking on a blockchain*
  - → *Distributed observation and validation of application executions*

→ ***Scalable Model-Based Decentralized Applications***

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