PDB Isolation and Security

What about security of Oracle multitenant container database (CDB)?

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- Since 1997 active in various IT areas and since 2008 with Trivadis AG
- More than 20 years of experience in Oracle databases
- Live with my family (wife and two kids) in Muri in a small village in CH

Focus: Protecting data and operating databases securely

- Security assessments and reviews
- Database security concepts and their implementation
- Oracle Backup & Recovery concepts and troubleshooting
- Oracle Enterprise User Security, Advanced Security, Database Vault, …
- Oracle Directory Services

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FOUNDED IN
1994

16 TRIVADIS WORKSPACES

SWITZERLAND, GERMANY, AUSTRIA, DENMARK, ROMANIA

118 MILLION CHF
TURNOVER

300 SLA's
(SERVICE LEVEL AGREEMENTS)

4000
TRAINING PARTICIPANTS PER YEAR

800
CUSTOMERS

700
EMPLOYEES

5 MILLION CHF
BUDGET FOR SCIENCE AND DEVELOPMENT PER YEAR

1900 PER YEAR
PROJECTS

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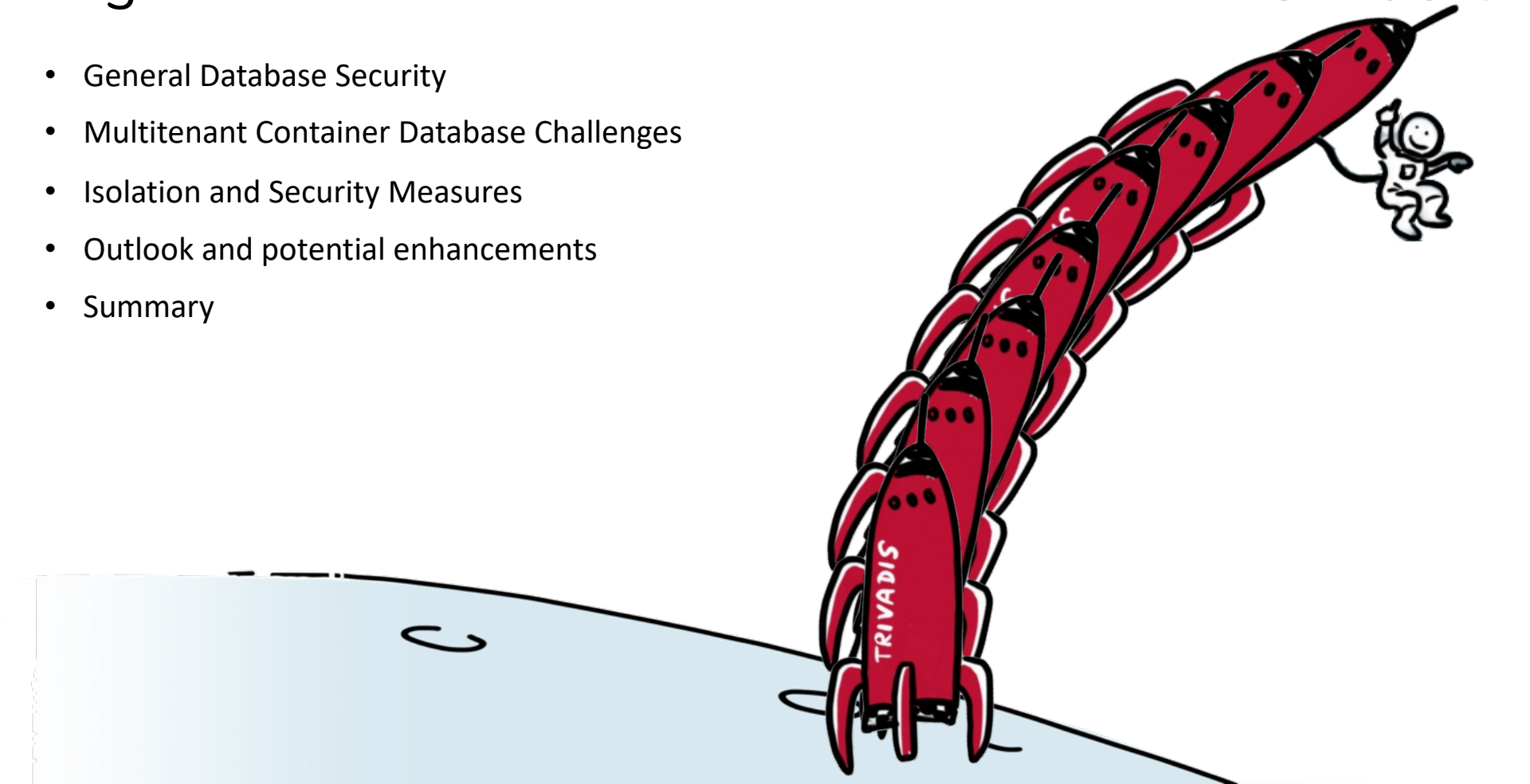
Agenda

- General Database Security
- Multitenant Container Database Challenges
- Isolation and Security Measures
- Outlook and potential enhancements
- Summary



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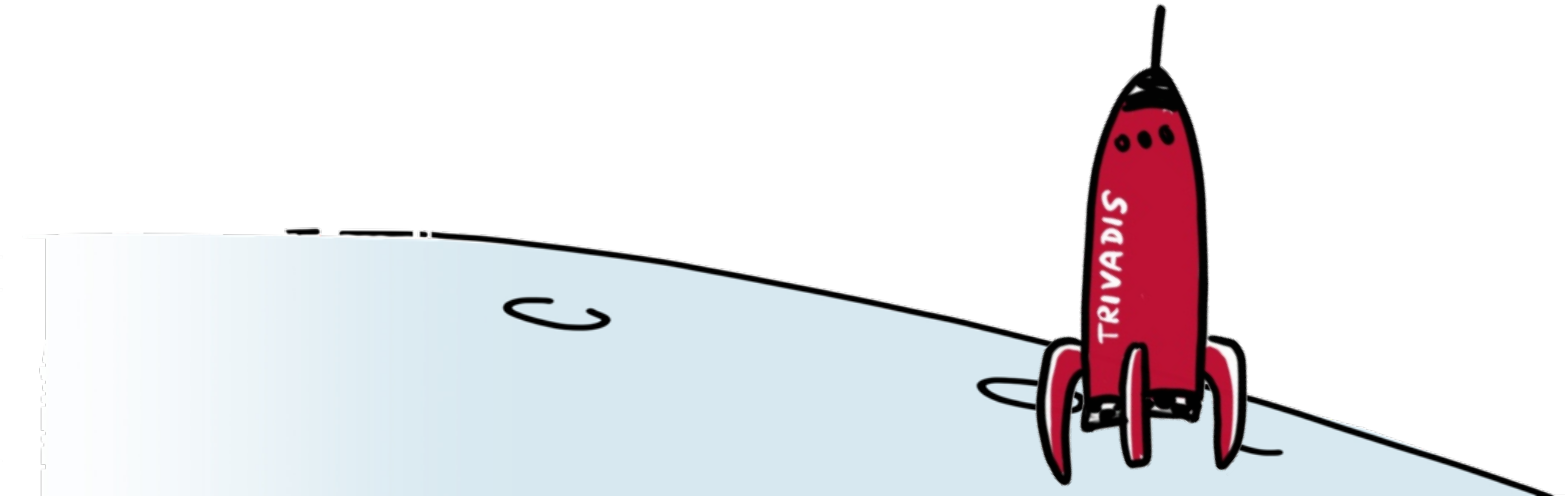

Top 10 Database Risks and Threats

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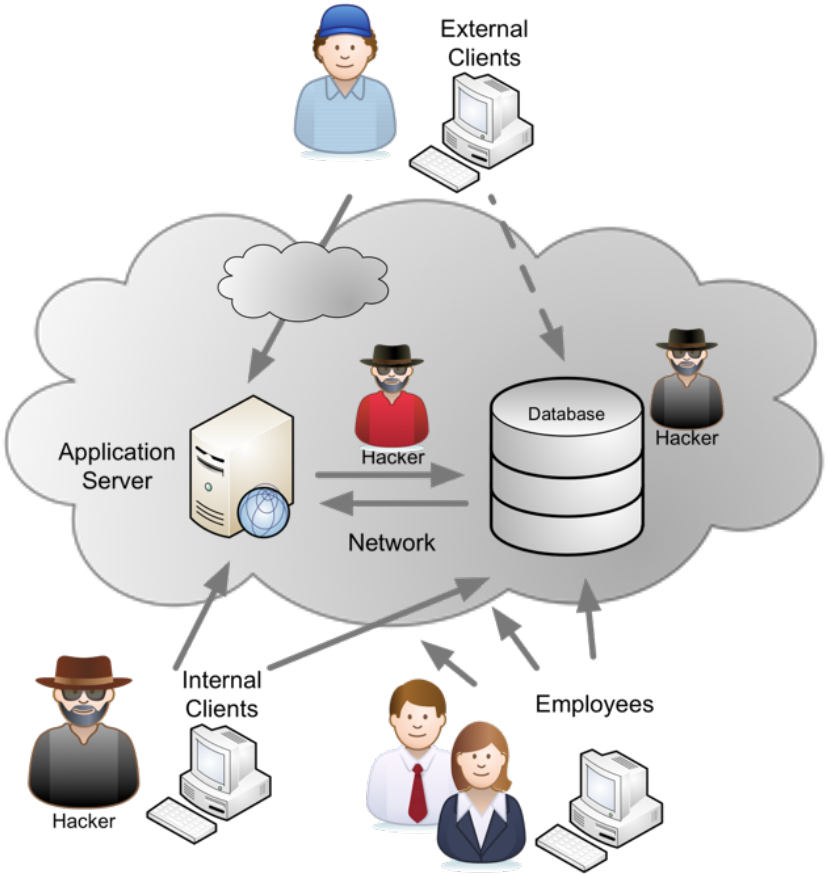
- Excessive privileges
- Privilege abuse
- Unauthorized privilege elevation
- Platform vulnerabilities
- SQL injection
- Weak audit
- Denial of service
- Database protocol vulnerabilities
- Weak authentication
- Exposure of backup data



Maximal Data Security Architecture

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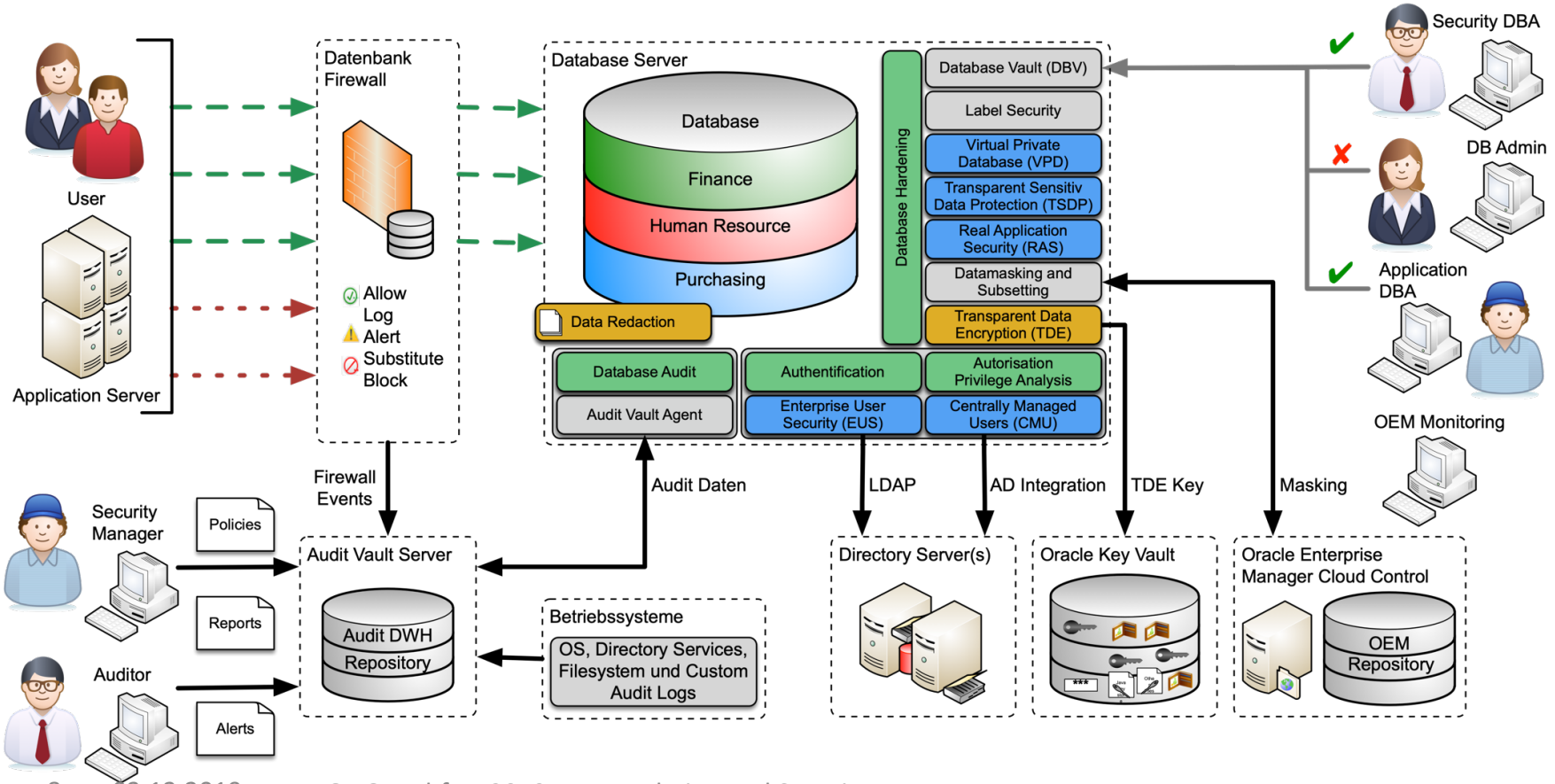

Maximal Data Security Architecture - CDB

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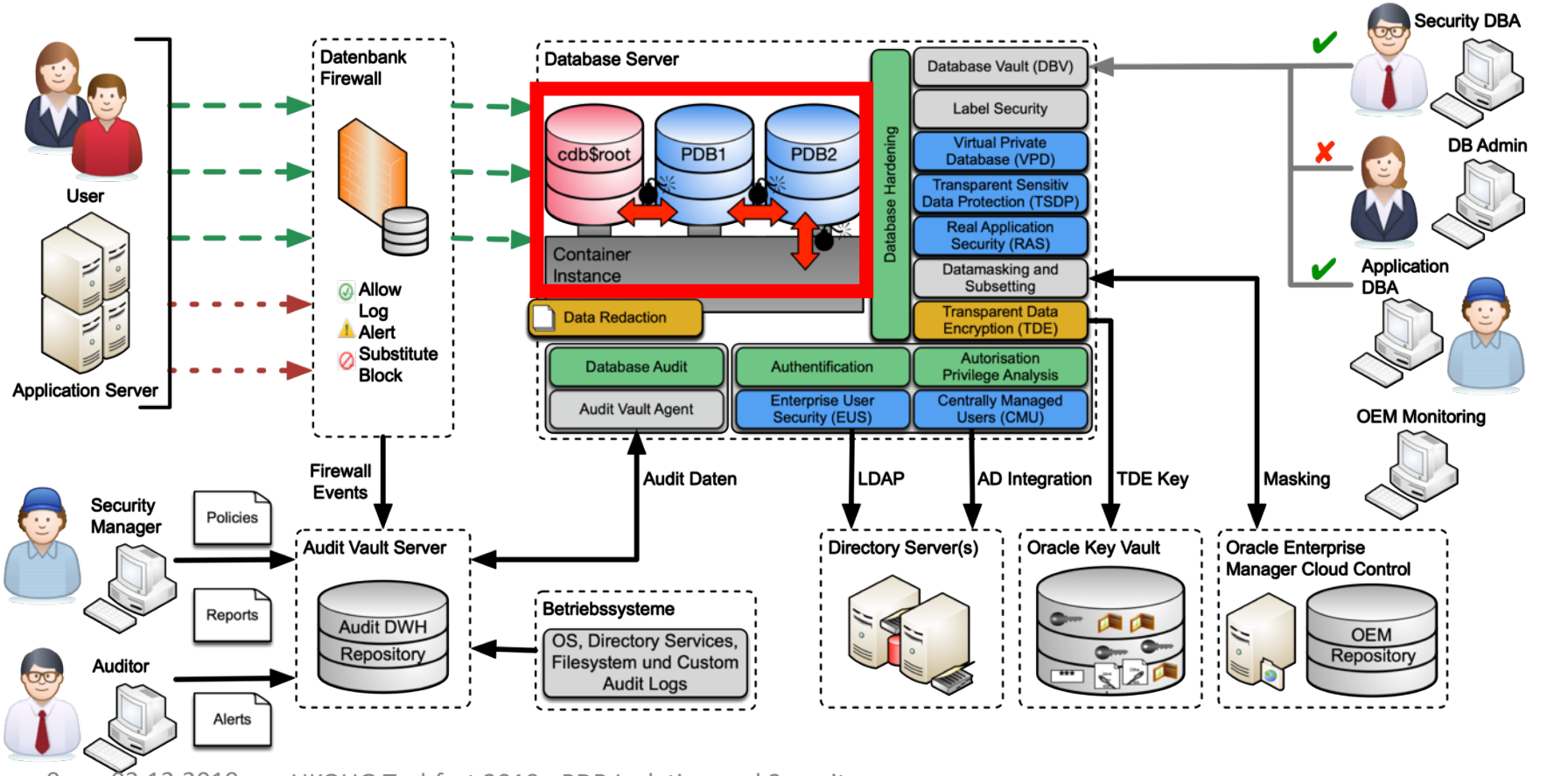

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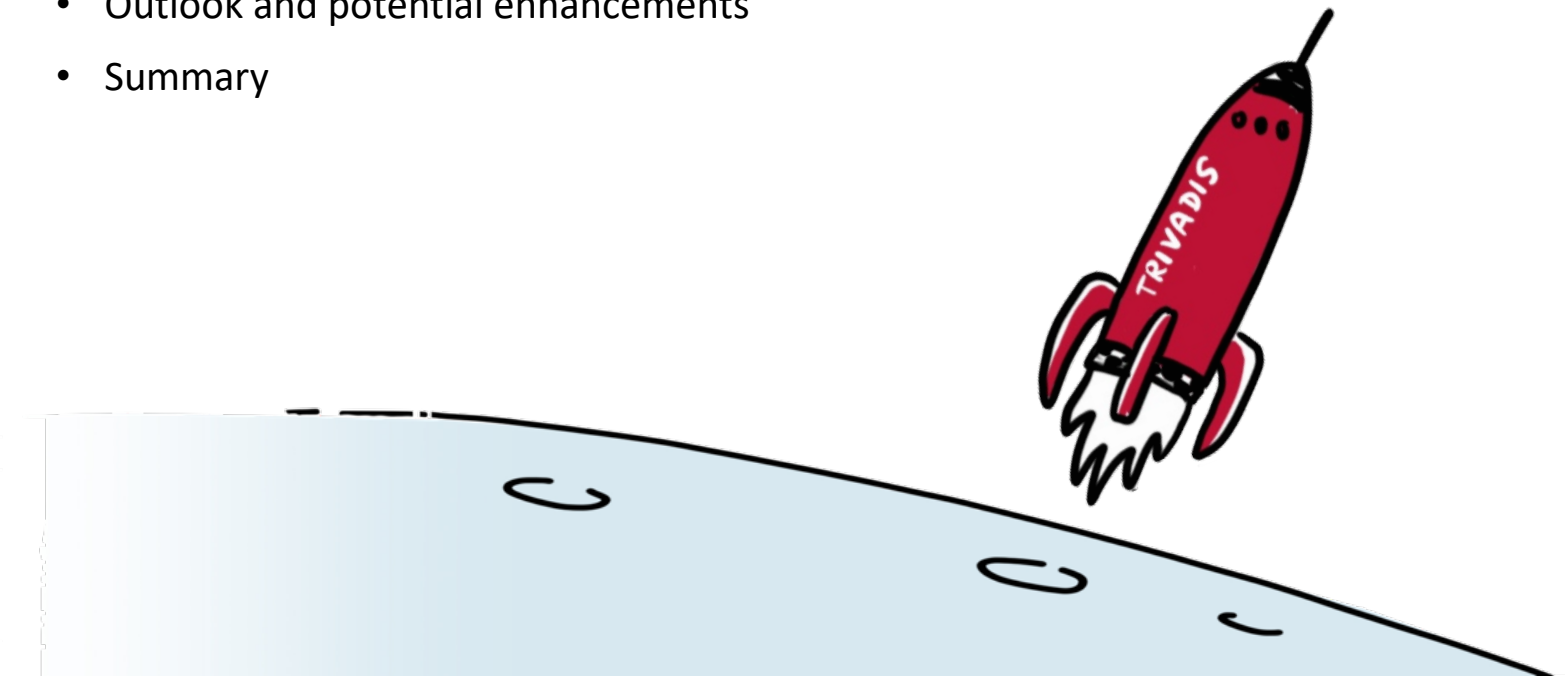

Multitenant Container Database Usage

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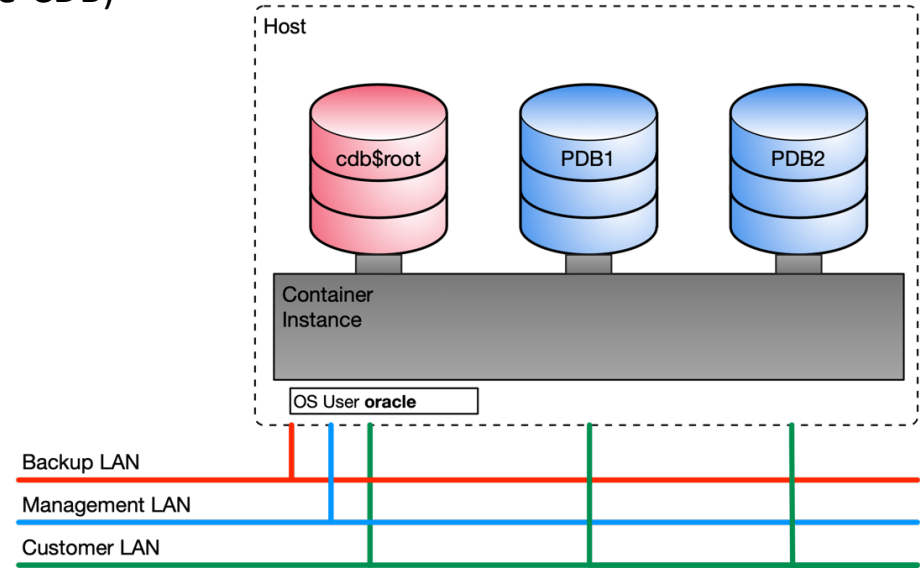
How are the multitenant container databases used?

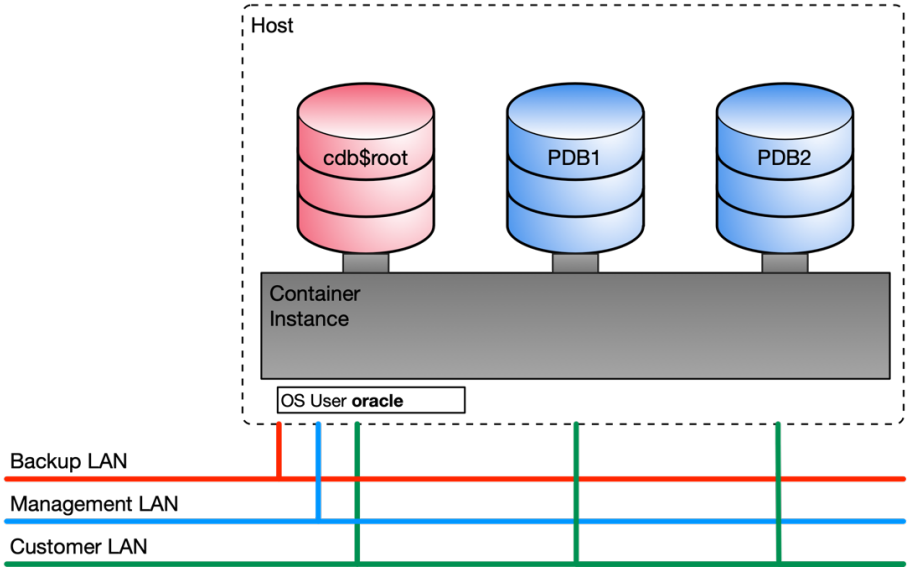
- Simple replacement of the classic database (none-CDB) architecture with just one PDB
- Database consolidation using multiple PDBs
- Private DBAAS
- Public DBAAS

Infrastructure architecture

- Cloud, Hybrid or on-premises?
- Dedicated hardware
- Virtual environments
- Engineered System



Multitenant Container Database Usage



Security related questions

- Comprehensive privileges available in PDBs
- Strict security requirements and standards
- Industry dependent legal and compliance requirements

Corporate structure

- All just one legal entity
- More or less independent departments
- Several companies and subsidiaries
- Service provider for different companies

Isolation requirements vary

But why isolation at all?

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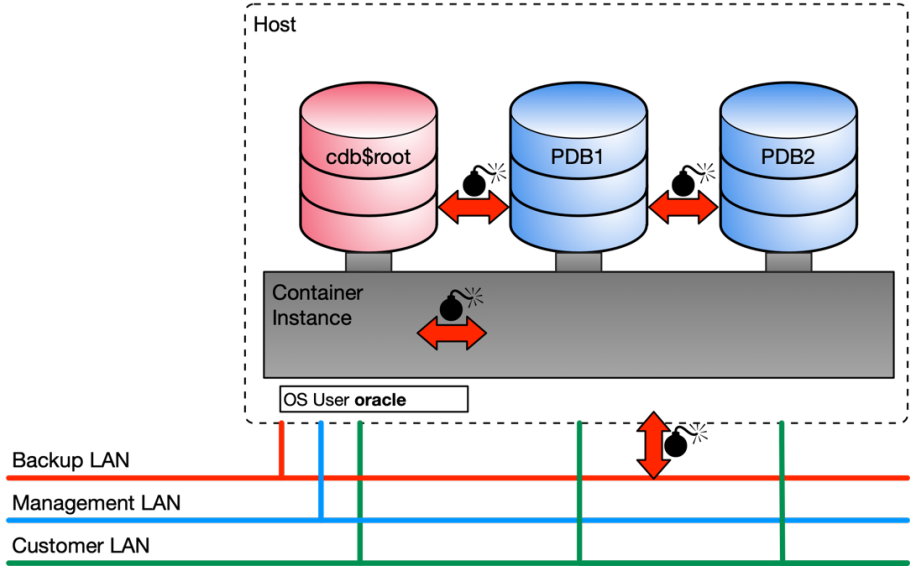
- Only basic database security is not enough...
- PDB admin and user do have comprehensive privileges (DBAAS).
  - Full DBA role
  - ALTER SYSTEM, ALTER SESSION,…
  - PL/SQL packages and procedures
- Oracle bugs **and** feature allow to escape the boundaries of a PDB.
  - Scheduler jobs including OS calls
  - External table pre-processor scripts
  - PL/SQL Library calls
  - Java OS calls
- Resource management beyond the scope of PDBs



Risks in a DBAAS environment

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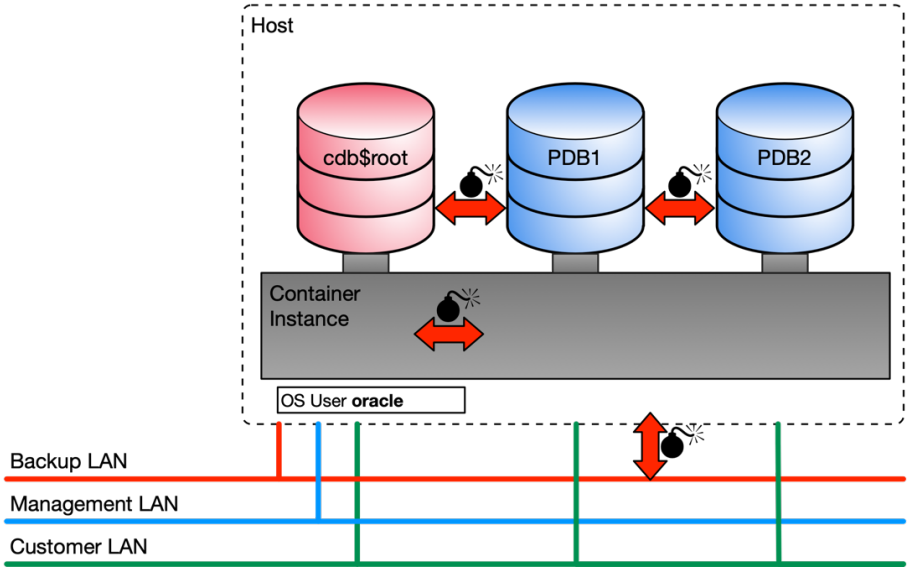

- PDB admin use **privilege escalation**.
- **Excessive** use of shared resources.
- Access sensitive data via shared resources e.g. backup or management LAN.
- Break out of PDB and get OS access as **oracle**.
- Gain access to the **root container** (cdb$root)
- Gain access to other PDBs.
- Gain access to the **network**.
- Use of **critical features** like
  - Administration features
  - Oracle JVM
  - DBMS_SCHEDULER
  - External table pre-processor

Risk all cleared?

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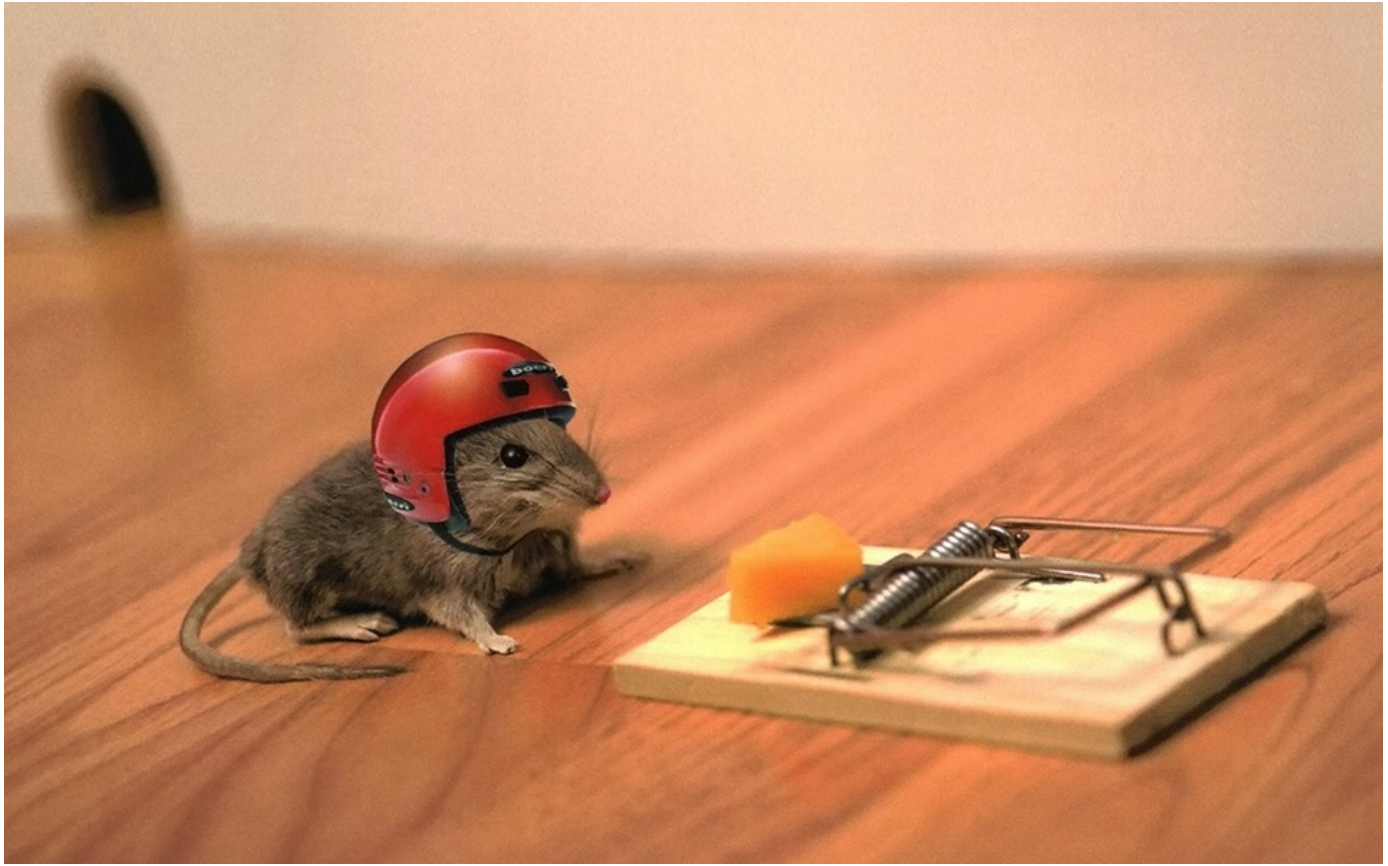

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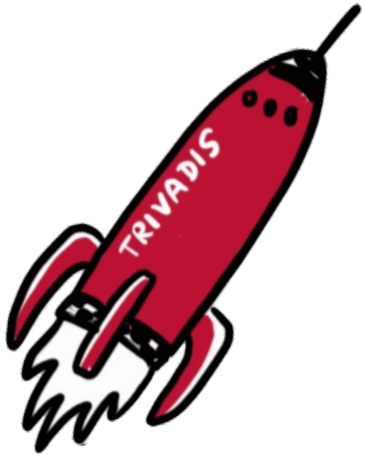

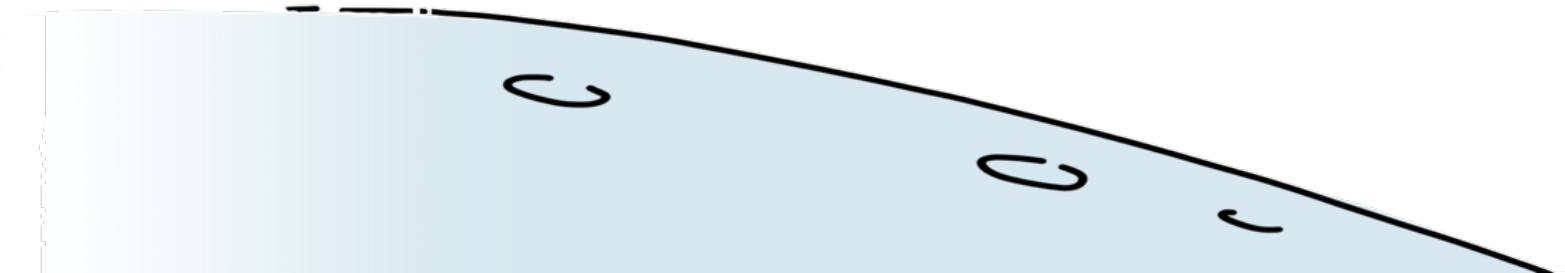

Are we cooking or why onions?

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- Measures on several levels are essential.
- Layered structure similar to an onion. e.g.
  - Secure and correct data
  - Secure application design
  - PDB hardening
  - PDB isolation and security
  - General CDB architecture
  - CDB hardening
  - OS Hardening
  - Network security
- The following functions such as lockdown profiles, path prefix and PDB OS credentials are only part of a holistic approach.

Possibilities for risk mitigation

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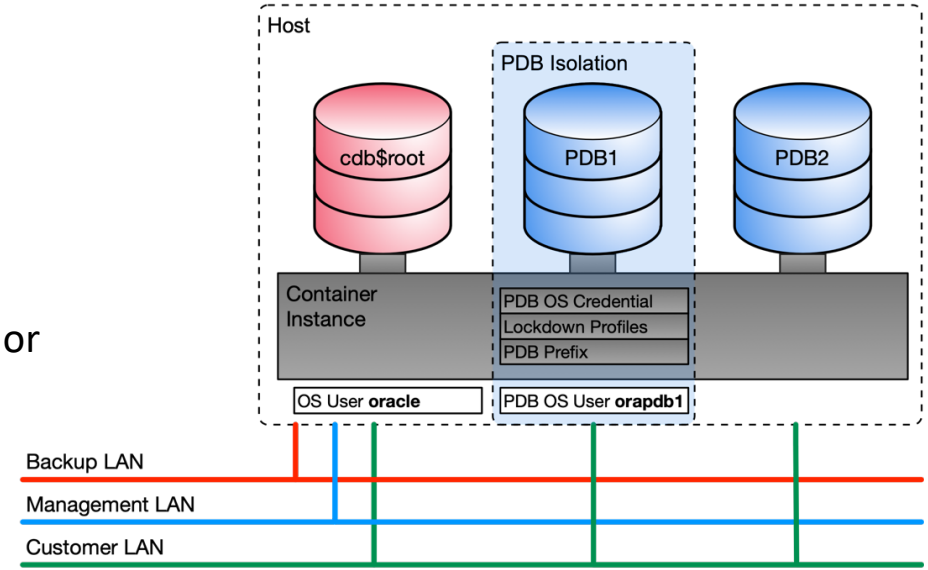
A multitenant container database provides the following features beyond regular security measures:

- **PATH_PREFIX** and **CREATE_FILE_DEST** clause to limit data files and directory objects to certain paths.
- **PDB_OS_CREDENTIAL** parameter assigning a dedicated user account for OS interactions
- **Lockdown profiles** to restrict certain operations or functionalities in a PDBs

But what can you do with them...?



Manage File Access

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PATH_PREFIX clause to restrict directory object paths

- Set per PDB at creation time. Can not be changed later.
- Restrictions and limitations when **PATH_PREFIX** is used:
  - Existing directory objects might not work as expected.
  - **PATH_PREFIX** string is always added as a prefix to all local directory objects in the PDB.
  - It does not apply to Oracle-supplied directory objects.
  - Does not affect files created by Oracle Managed Files nor data files or temporary files
  - Issues when using / allowing **softlinks**

CREATE_FILE_DEST clause to restrict directory path for data files or temporary files.

- Implicit set DB_CREATE_FILE_DEST. => can be modified / requires lockdown profile
- Enable Oracle Managed Files for the PDB.
- Specifies the default file system directory or Oracle ASM disk group for PDB files.

Configure File Access

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- Manually create a PDB based on PDB$SEED

```
CREATE PLUGGABLE DATABASE pdbsec
    ADMIN USER pdbadmin IDENTIFIED BY LAB01schulung ROLES=(dba)
    PATH_PREFIX = '/u01/oradata/pdbsec/directories/'
    CREATE_FILE_DEST = '/u01/oradata/pdbsec/';
```

- Alternatively create a PDB based on a template PDB, dbca etc.
- Check current setting of PATH_PREFIX in `database_properties`

```
ALTER SESSION SET CONTAINER=pdbsec;
SELECT * FROM database_properties WHERE property_name='PATH_PREFIX';

PROPERTY_NAME PROPERTY_VALUE                    DESCRIPTION
------------- --------------------------------- ----------------------
PATH_PREFIX   /u01/oradata/PDBSEC/directories All paths for objects
                                                such as directories
                                                are relative to this
```

Verify File Access – PATH_PREFIX

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- Create an Oracle directory object outside PATH_PREFIX

```
SQL> CREATE DIRECTORY wrong_prefix AS '/tmp/test';
CREATE DIRECTORY wrong_prefix AS '/tmp/test'
*
ERROR at line 1:
ORA-65254: invalid path specified for the directory
```

- Create an Oracle directory object inside PATH_PREFIX

```
SQL> CREATE DIRECTORY no_prefix AS 'no_prefix';

Directory created.

SQL> SELECT directory_name, directory_path FROM dba_directories
  2  WHERE origin_con_id=(SELECT con_id FROM v$pdbs);

DIRECTORY_NAME DIRECTORY_PATH
-------------- ----------------------------------------
NO_PREFIX /u01/oradata/PDBSEC/directories/no_prefix
```

Verify File Access – CREATE_FILE_DEST

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- Create an Oracle tablespace with an absolute path outside CREATE_FILE_DEST

```
SQL> CREATE TABLESPACE wrong_prefix DATAFILE '/tmp/wrong_prefix.dbf' SIZE
1M;
CREATE TABLESPACE wrong_prefix DATAFILE '/tmp/wrong_prefix.dbf' SIZE 1M
*
ERROR at line 1:
ORA-65250: invalid path specified for file - /tmp/wrong_prefix.dbf
```

- Create an Oracle tablespace with an absolute path within CREATE_FILE_DEST and with OMF

```
SQL> CREATE TABLESPACE right_prefix DATAFILE
  2  '/u01/oradata/PDBSEC/right_prefix.dbf' SIZE 1M;
Tablespace created.

SQL> CREATE TABLESPACE no_prefix datafile SIZE 1M;

Tablespace created.
```

Manage File Access, but…

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Unfortunately one might stumble over the **PATH_PREFIX** now and then:

- PATH_PREFIX should no apply to Oracle-supplied directory objects. Says the Oracle Documentation:

> - The `PATH_PREFIX` clause only applies to user-created directory objects. It does not apply to Oracle-supplied directory objects.

- … but what is an Oracle supplied directory?
- Automated Tablespace Point in Time Recovery (TS PITR) do not work. RMAN can not create the directory to transfer the Tablespace (SR still under investigation)
- Datapatch could have issues see Bug 25074866 and Patch 25074866 for 12c R2

Managing OS Access

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- Define a dedicated OS user account for system interactions.
- Based on **DBMS_CREDENTIAL** package and init parameter **PDB_OS_CREDENTIAL**.
- Introduced with Oracle 12.2.0.1.
- Allows to define dedicated OS credential for:
  - External jobs that do not yet have an OS credential specified
  - External table pre-processors
  - PL/SQL library executions (EXTPROC)
- Can be defined globally or per PDB.

As far as theory goes...

- ... unfortunately there are still bugs (12g-19c)
- … PDB_OS_CREDENTIAL does not work as expected for table pre-processor (DBMS_SCHEDULER fixed since yesterday for 12.2.0.1 RU April 2019)

Define credentials

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- Create a credential in the *cdb$root* for a corresponding OS user

```
BEGIN
    dbms_credential.create_credential(
    credential_name => 'PDBSEC_OS_USER',
    username        => 'orapdbsec',
    password        => 'manager');
END;
/
```

- Set the parameter at CDB level (older version did require a change via pfile)

```
ALTER SYSTEM SET pdb_os_credential=GENERIC_PDB_OS_USER SCOPE=SPFILE;
```

- Or individually per PDB

```
ALTER SESSION SET CONTAINER=pdbsec;
ALTER SYSTEM SET pdb_os_credential=PDBSEC_OS_USER SCOPE=SPFILE;
```

Lockdown Profiles

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- Oracle introduced lockdown profiles with 12.1. However, they become interesting only in 12.2 or the better 18c/19c
- Lockdown profiles allows to restrict user operation in PDBs in a multitenant container database.
- It is possible to assign lockdown profiles to...
  - ... individual PDBs, if PDB_LOCKDOWN is set while connected to a particular PDB.
  - ... all PDBs in a CDB, if PDB_LOCKDOWN is set while connected to the CDB root.
  - … application container, if PDB_LOCKDOWN is set while connected to an application root
- The `CREATE LOCKDOWN PROFILE` statement must be issued from CDB or application root.
- Usage of lockdown profiles includes 3 steps:
  - Create a lockdown profile using `CREATE LOCKDOWN PROFILE`
  - Enable / disable user operations using `ALTER LOCKDOWN PROFILE`
  - Enable the corresponding lockdown profile using `ALTER SYSTEM SET pdb_lockdown=`

Capabilities of Lockdown Profiles

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- `ALTER LOCKDOWN PROFILE` statement allows to enable or disable the following functions :
  - *LOCKDOWN_OPTIONS* clause: User operations associated with certain database options.
  - *LOCKDOWN_FEATURES* clause: User operations associated with certain database features.
  - *LOCKDOWN_STATEMENTS* clause: The issuance of certain SQL statements.
- Function can either explicitly be disable or enable.
- Combination of ALL and EXCEPT is possible.
- Oracle 18c introduced a couple of enhancements for lockdown profiles:
  - Restrict user operation for ALL, LOCAL or COMMON user.
  - Create lockdown profiles based existing profiles as static copy or dynamic link.

LOCKDOWN_OPTIONS clause

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- The following database options can be restricted:
  - DATABASE QUEUING – User operations associated with Oracle Database Advanced Queuing option
  - PARTITIONING – User operations associated with Oracle Partitioning option
- Restriction explicit or with exclusion:
  - Use ALL to specify all options.
  - Use ALL EXCEPT to specify all options except the specified options.
  - Default is ENABLE OPTION ALL.
- Enable all options except DATABASE QUEUING

```
ALTER LOCKDOWN PROFILE sec_default ENABLE OPTION
ALL EXCEPT = ('DATABASE QUEUING');
```

LOCKDOWN_FEATURES clause

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- *LOCKDOWN_FEATURES* clause disable or enable user operations associated with certain database features.
- Supports a comprehensive list of database features and feature bundle e.g. AWR_ACCESS, CONNECTIONS, JAVA, JAVA_RUNTIME, NETWORK_ACCESS, OS_ACCESS, etc.
  - See Oracle documentation ALTER LOCKDOWN PROFILE for a complete list.
- Restriction explicit or with exclusion:
  - Use ALL to specify all features.
  - Use ALL EXCEPT to specify all features except the specified feature.
  - Default is ENABLE ALL.
- Disable OS_ACCESS but explicitly enable TRACE_VIEW_ACCESS

```
ALTER LOCKDOWN PROFILE sec_default DISABLE FEATURE = ('OS_ACCESS');
ALTER LOCKDOWN PROFILE sec_default ENABLE FEATURE = ('TRACE_VIEW_ACCESS');
```

LOCKDOWN_STATEMENTS clause

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- *LOCKDOWN_ STATEMENTS* clause disable or enable issuance of certain SQL statements.
  - Use DISABLE to disable the execution of specified SQL statements.
  - Use ENABLE to enable the execution of specified SQL statements.
- Restriction explicit or with exclusion:
  - Use ALL to specify all statements.
  - Use ALL EXCEPT to specify all statements except the specified statements.
  - Default is ENABLE STATEMENT ALL.
- The STATEMENT_CLAUSES lets disable or enable specific clauses of the specified SQL statement.
- The OPTION_CLAUSES lets disable or enable setting or modification of specific options.
  - E.g. disable all `ALTER SYSTEM` but allow `ALTER SYSTEM SET cursor_sharing`
- Challenging to cover all critical statements, clause and options and not open a security flaw.

A few more examples

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- Disable `ALTER SYSTEM` but allow it for `COMMON` user and for clause `KILL SESSION`.

```
ALTER LOCKDOWN PROFILE sec_default DISABLE STATEMENT = ('ALTER SYSTEM');
ALTER LOCKDOWN PROFILE sec_default ENABLE
    STATEMENT = ('ALTER SYSTEM') CLAUSE = ('SET') USERS=COMMON;
ALTER LOCKDOWN PROFILE sec_default ENABLE
    STATEMENT = ('ALTER SYSTEM') CLAUSE = ('KILL SESSION');
```

- Create a new lockdown profile **sec_jvm** based on **sec_default**
- Enable Java and Java runtime

```
CREATE LOCKDOWN PROFILE sec_jvm FROM sec_default;
ALTER LOCKDOWN PROFILE sec_jvm ENABLE FEATURE = ('JAVA_RUNTIME');
ALTER LOCKDOWN PROFILE sec_jvm ENABLE FEATURE = ('JAVA');
```

Missing parts

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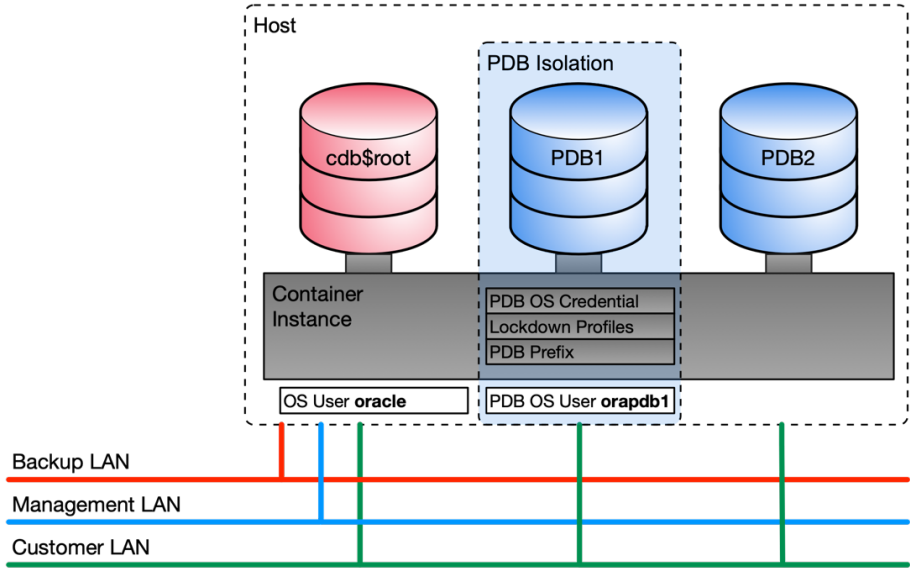
- PDB isolation is no a replacement for a comprehensive security concept.
- Resource management is not covered at all.
- TDE, in particular TDE key management requires additional measures
- OS specific admin activities are not separated. e.g. Backup & Recover
- Although user are distinct by PDB_OS_CREDENTIAL, measures on the OS are still mandatory. => Layered Security
- Flaw in PDB isolation if poor lockdown profiles have been defined.



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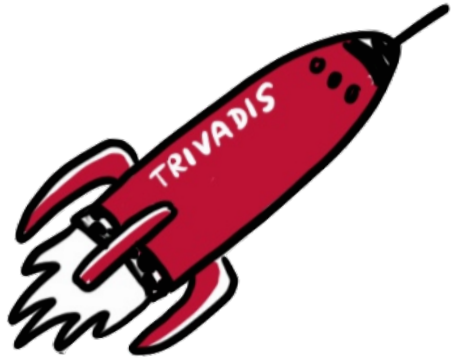

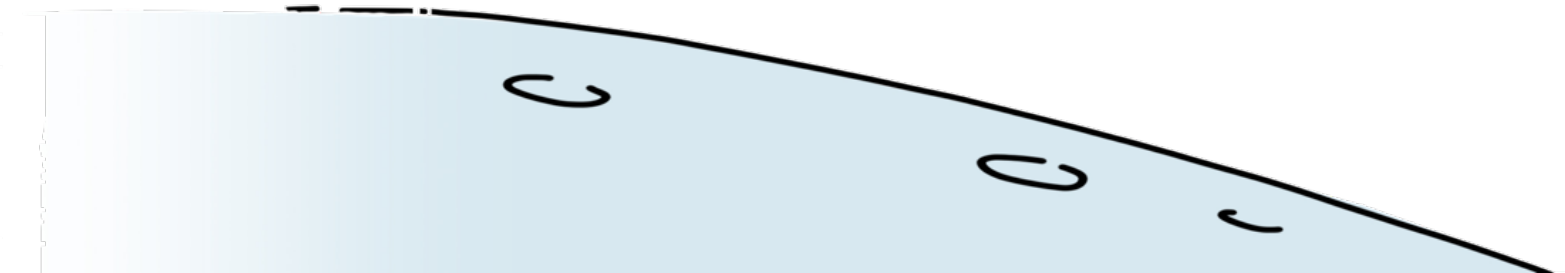

Outlook and potential enhancements

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- In short term, waiting for the problems around PDB_OS_CREDENTIAL to be solved is still required.
  - Bug 25820082 - PDB_OS_CREDENTIAL PARAMETER NOT WORKING
    => fixed for 12.2.0.1 RU April 2019 since 10. Sept. 2019
  - Bug 29926986 - LISTENER SPAWNED EXTPROC FAILS WITH ORA-28575
  - Bug 29922316 - EXTPROC FAILS WITH HS: CHILD EXTPROC FINISHED CALLING JSSU! STATUS = -1 WHEN DBMS_CREDENTIAL CONFIGURED
  - Doc 29938722 - PDB_OS_CREDENTIAL DOCUMENTION NEEDS TO INCLUDE CONFIGURATION REQUIREMENTS AND EXAMPLES
  - MOS Note 2296226.1 datapatch Fails With "ORA-65254: invalid path specified for the directory" on PDB where PATH_PREFIX is set)
- Although the Java challenges are not yet covered by these bugs
- Oracle does struggle with similar challenges for their cloud services e.g. Oracle Autonomous Database.

Oracle DB Nest

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- A possible hint in Oracle 19c based on a few hidden parameter

```
Parameter                 Instance    Description
------------------------- ----------- --------------------------------
_dbnest_enable            NONE        dbNest enable
_dbnest_pdb_fs_conf                   PDB Filesystem configuration
_dbnest_pdb_fs_type       DEFAULT     PDB FS Type
_dbnest_pdb_scm_conf                  PDB SCM configuration
_dbnest_pdb_scm_level     STRICT1     PDB SCM Level
_dbnest_stage_dir                     Staging directory configuration
_instance_dbnest_name                 Instance dbNest Name
```

- Reveals a functionality named DB Nest.
- Presentations from OOW 2018 have mentioned DB Nest as a security enhancement for Multitenant Databases.
- Discussions with the Oracle PM for PDBs have shown that solutions are needed and being developed. e.g. Linux CGROUPS, Linux Security Module (LSM) etc.

Oracle DB Nest

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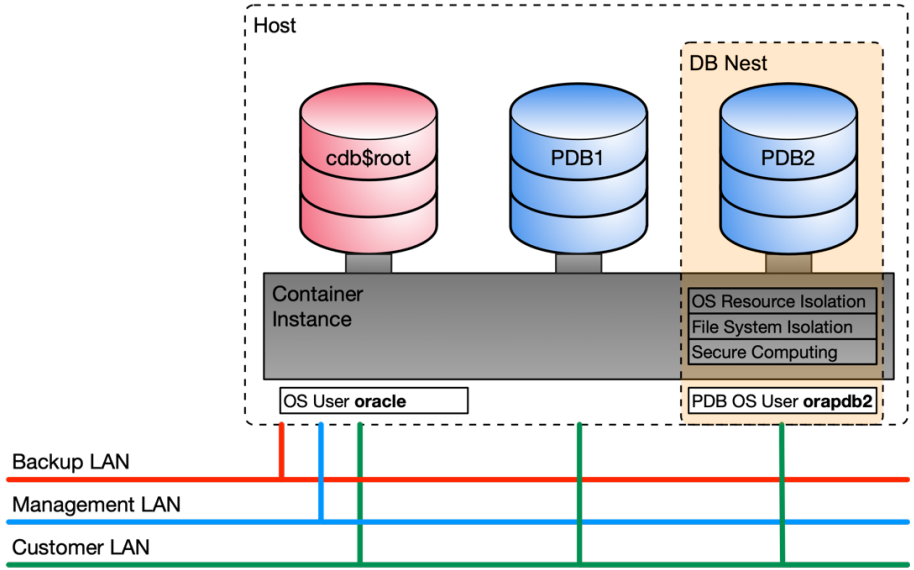
The exact functionality can only be guessed at the moment.

Control and isolation of...

- OS resources used by a PDB
- File system isolation per PDB
- Secure computing
- …?

Next Oracle Open World / Oracle Release coming soon ☺



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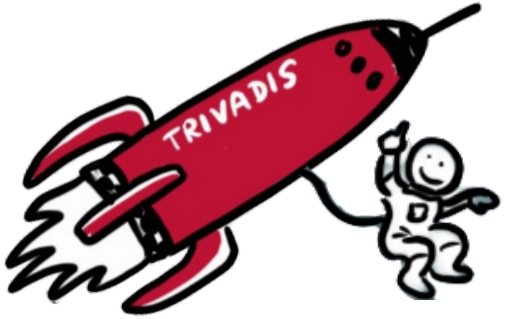

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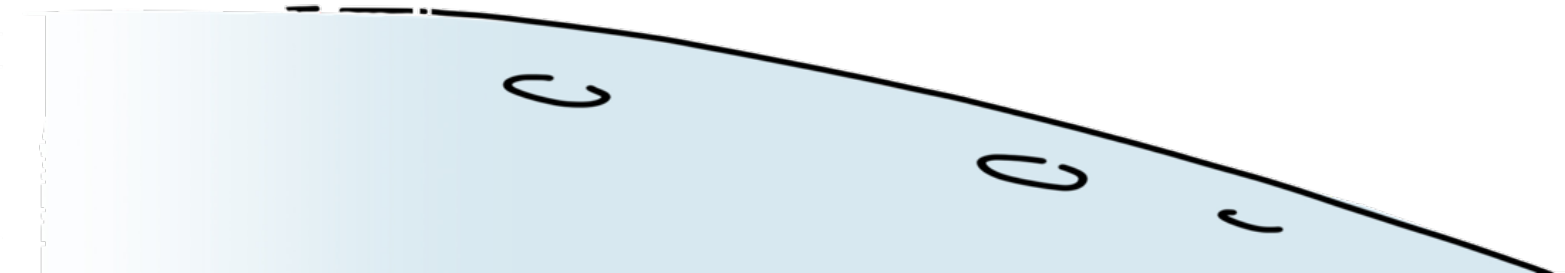

Summary

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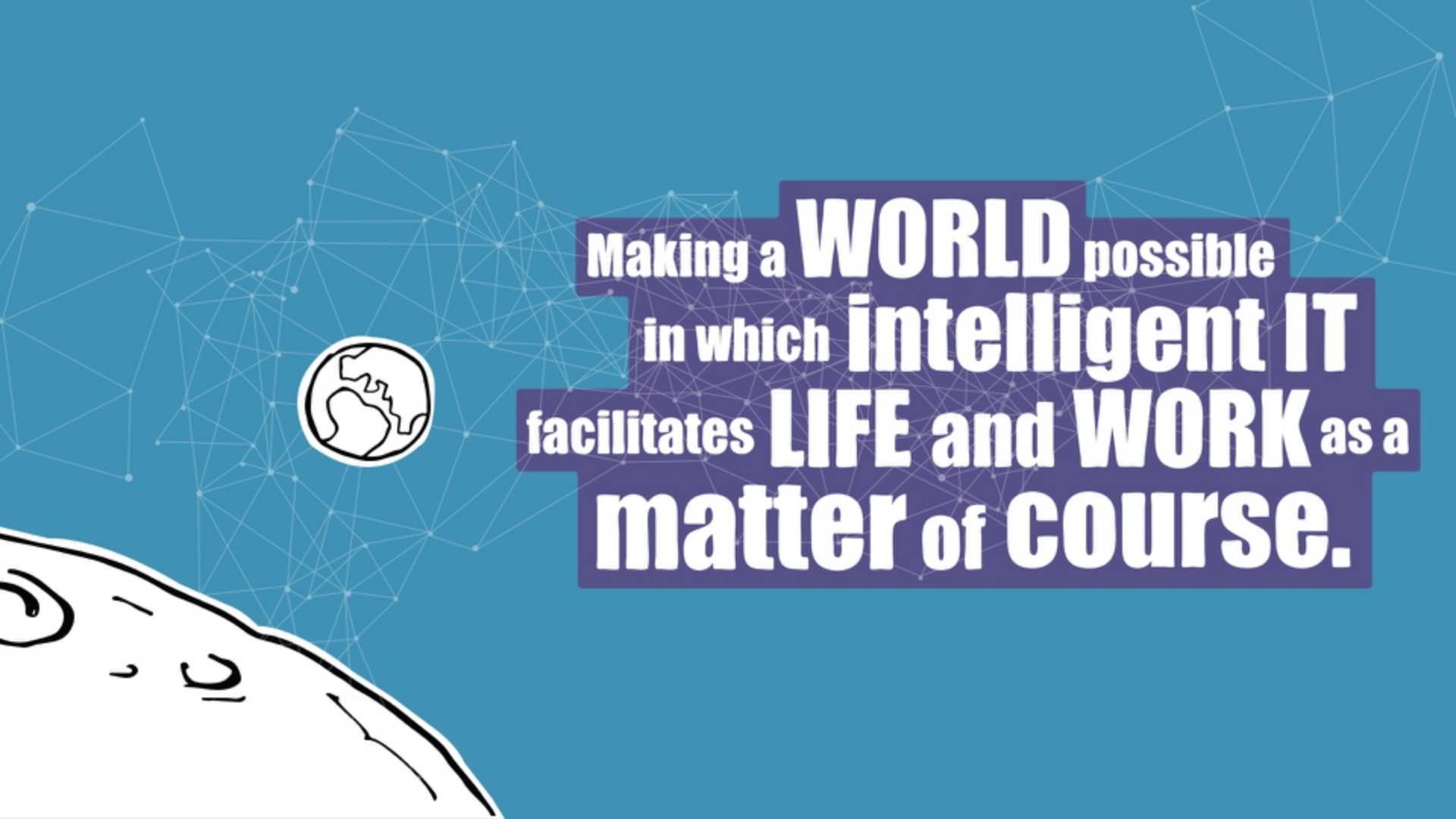
- It is not exclusively a customer challenge. Oracle has to solve similar issues for its cloud products.
- Lockdown profiles, PATH_PREFIX, PDB_OS_CREDENTIAL etc. do provide basic functionality to implement PDB Isolation. But…
  - … there are still a few bugs.
  - … not all use cases are covered e.g. resource management, java etc.
- What used to be true is still true.
  - **Do not install** Oracle JVM in security-critical databases!
  - If it is not absolutely necessary.
- The opening of an SR on this topic is simply cumbersome and laborious.
- The new functionality DB Nest does look promising.

Despite the limitations, these functions offer basic functionalities to make the PDB more secure and to start implementing isolation.


Making a WORLD possible
in which intelligent IT
facilitates LIFE and WORK as a
matter of course.