14. Design Space Explorer

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Introduction

The Quartus® II software includes many advanced optimization algorithms to help you achieve timing closure, optimize area, and reduce dynamic power. The various settings and parameters control the behavior of the algorithms. These options provide complete control over the Quartus II software optimization and power techniques.

Each FPGA design is unique. There is no standard set of options that always results in the best performance or power utilization. Each design requires a unique set of options to achieve optimal performance. This chapter describes Design Space Explorer (DSE), a utility written in Tcl/Tk that automates finding the best set of options for your design. DSE explores the design space of your design by applying various optimization techniques and analyzing the results.

DSE is a valuable tool to use in the late phases of your design cycle. You can take advantage of DSE's capability to automatically sweep multiple options to close timing, minimize area, or reduce power consumption on a design that is nearing completion.

DSE Concepts

This section explains the concepts and terminology used by DSE.

Exploration Space and Exploration Point

Before DSE explores a design, DSE creates an exploration space, which consists of Synthesis and Fitter settings available in the Quartus II software. Each group of settings in an exploration space is referred to as a point. An exploration space contains one or more points. DSE traverses the points in the exploration space to determine optimal settings for your design.

Seed and Seed Sweeping

The Quartus II Fitter uses a seed to specify the starting value that randomly determines the initial placement for the current design. The seed value can be any non-negative integer value. Changing the starting value may or may not produce better fitting. However, varying the value of the seed or seed sweeping allows the Quartus II software to determine an optimal value for the current design.

DSE extends Fitter seed sweeping in exploration spaces by providing a method for sweeping through general compilation and Fitter parameters to find the best options for your design. You can run DSE in various exploration space modes, ranging from an exhaustive try-all-options-and-values mode to a mode that focuses on one parameter.

DSE Exploration

DSE compares all exploration point results with the results of a base compilation, generated from the initial settings that you specify in the original Quartus II project files. As DSE traverses all points in the exploration space, all settings not explicitly modified by DSE default to the base compilation setting. For example, if an exploration point turns on register retiming but does not modify the register packing setting, the register packing setting defaults to the value you specified in the base compilation.

DSE performs the base compilation with the settings you specified in the original Quartus II project. These settings are restored after DSE traverses all points in the exploration space. DSE makes a copy of your base revision and uses this copy for changing the settings required to traverse through all other points in the chosen exploration space. Your base revision is not affected by DSE exploration.

General Description

You can use DSE in either the graphical user interface (GUI) or from a command line. To run DSE with the GUI, either click **Launch Design Space Explorer** on the Tools menu in the Quartus II software, or type the following at the command prompt:

```
quartus_sh --dse ↵
```

To run DSE from a command line, type the following command at the command prompt:

```
quartus_sh --dse -nogui [<options>] ↵
```

You can run DSE with the following options:

```
-archive
-concurrent-compiles [0..6]
-custom-file <filename>
-decision-column <"column name">
-exploration-space <"space">
-ignore-failed-base
-llr-restructuring
-lower-priority
-lsf-queue <queue name>
-nogui
-optimization-goal <"goal"
-report-all-resource-usage
-project <project name>
-revision <revision name>
-run-power
-search-method <"method">
-seeds <seed list>
-skip-base
-slaves <"slave1, slave2, slave3......">
-stop-after-time <dd:hh:mm>
-stop-after-zero-failing-paths
-use-lsf
```

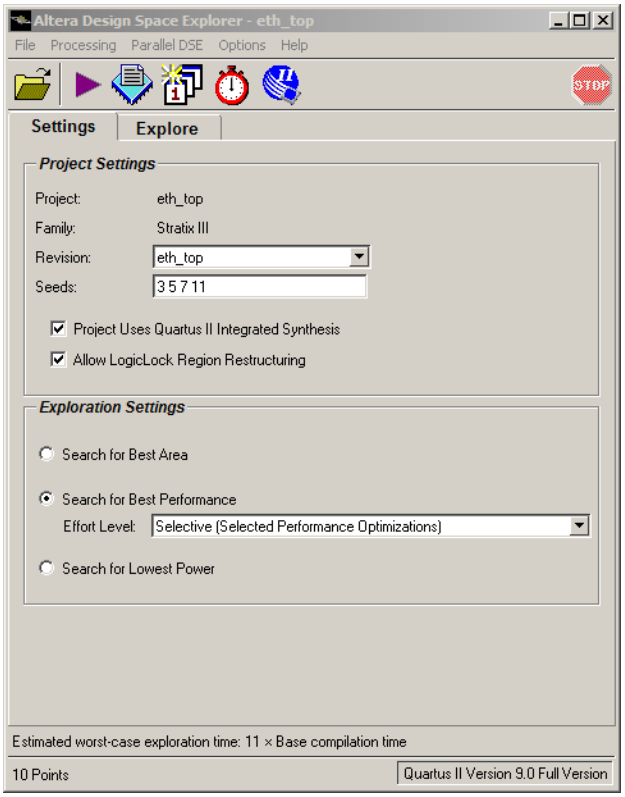
DSE script **dse.tcl** is located in <*Quartus II installation directory*>**/common/tcl/apps/dse** on Windows and Linux operating systems.

To launch DSE from the Quartus II software user interface, on the Tools menu, click **Launch Design Space Explorer**.

For more information about DSE, launch the DSE GUI. On the **Help menu**, click **Contents** or press the F1 key.

Figure 14–1 shows DSE user interface. The **Settings** tab is divided into two sections: **Project Settings** and **Exploration Settings**.

Figure 14–1. DSE User Interface



Timing Analyzer Support

DSE supports both the Quartus II Classic Timing Analyzer and the Quartus II TimeQuest Timing Analyzer. You must set the timing analyzer prior to opening the project in DSE. After the timing analyzer is set, DSE performs the design exploration with the selected timing analyzer.

You can directly launch the TimeQuest Timing Analyzer from DSE if you have set the default timing analyzer to TimeQuest and have specified the timing constraints in an **.sdc** file.

DSE Flow

You can run DSE at any point in the design process. However, Altera recommends that you run DSE late in your design cycle when your focus is on optimizing performance and power. The results gained from different combinations of optimization options early in the design cycle may not persist over large changes in a design.

DSE runs the Quartus II software for every point in the exploration space. The Quartus II software always attempts to achieve all your timing requirements regardless of whether or not you are running DSE. The **Exploration Settings** you choose in DSE will determine the settings to be used for compilation. DSE does not change the behavior of the Quartus II software.

DSE provides a summary of results for all the compilations and flags the best compilation run based on exploration setting you have chosen. Specifying all timing requirements before you use DSE to explore your design is very important to ensure that DSE finds the optimal set of parameters for your design based on design criteria you set in your initial design.

You can change the initial placement configuration used by the Quartus II Fitter by varying the **Fitter Seed** value. You can enter seed values in the **Seeds** field of DSE user interface.

To set the seed value in the Quartus II software, on the Assignments menu, click **Settings** and select **Fitter Settings**.

Compilation time increases as DSE exploration spaces become more comprehensive. Increased compilation time results from running several compilations and comparing the generated results with the original base compilation results.

For a typical design, varying only the seed value varies the f_{MAX} within a range of +/-5%. For example, when compiling with three different seeds, one-third of the time f_{MAX} does not improve over the initial compilation, one-third of the time f_{MAX} improves by 5%, and one-third of the time f_{MAX} improves by 5%.

DSE Support for Altera Device Families

DSE support varies across Altera device families. The Stratix® series of devices, the Cyclone® series of devices, and the Arria® GX series of devices can take advantage of all the available DSE optimization methods. The MAX® II series of devices and older families, such as the APEX™ series of devices and the FLEX® series of devices, support a subset of DSE options.

DSE Project Settings

This section provides the following information about DSE project settings:

- Setting up DSE work environment
- Specifying the revision
- Setting the initial seed
- Quartus II integrated synthesis
- Restructuring LogicLock regions

Setting Up the DSE Work Environment

From the DSE GUI, you can open a Quartus II project for a design exploration by clicking **Open Project** on the File menu and then browsing to your project. Clicking on the Quartus II icon in the DSE GUI closes the DSE GUI and opens the project.

Specifying the Revision

You can specify the revision to be explored with the **Revision** field in the DSE GUI. The **Revision** field is populated after the Quartus II project has been opened.

If no revisions were created in the Quartus II project, the default revision, which is the top-level entity, is used. For more information, refer to the *Managing Quartus II Projects* chapter in volume 2 of the *Quartus II Handbook*.

Setting the Initial Seed

To specify the seed that DSE uses for an exploration, specify a non-negative integer value in the **Seeds** box under **Project Settings** on the **Settings** tab. The seed value determines your design's initial placement in a Quartus II compilation.

To specify a range of seeds, type the low end of the range followed by a hyphen, followed by the high end of the range. For example, 2-5 specifies that DSE uses the values 2, 3, 4, and 5 as seeds.

Project Uses Quartus II Integrated Synthesis

Make sure to check the **Project Uses Quartus II Integrated Synthesis** option if you use Quartus II integrated synthesis to synthesize your design. The DSE explores several options that affect, and can help, the synthesis stage of compilation when this option is enabled.

For more information about integrated synthesis options, refer to the *Quartus II Integrated Synthesis* chapter in volume 1 of the *Quartus II Handbook*.

Restructuring LogicLock Regions

The **Allow LogicLock Region Restructuring** option allows DSE to modify LogicLock region properties in your design, if any exist. DSE applies the Soft property to LogicLock regions to improve timing. In addition, DSE can remove LogicLock regions that negatively affect the performance of the design.

DSE makes a copy of your base revision and modifies the LogicLock region settings on the new copy to see if the timing improves with the **Allow Logiclock Region Restructuring** option. Your original revision remains intact.

Exploration Settings

Use the **Exploration Settings** list to select the type of exploration to perform: **Search for Best Area**, **Search for Best Performance**, or **Search for Lowest Power**.

The **Search for Best Area** option uses a predefined exploration space that targets device utilization improvements for your design.

The **Search for Best Performance** option uses a predefined exploration space that targets performance improvements for your design. Depending on the device that your design targets, you can select up to five predefined exploration spaces: **Low** (**Seed Sweep**), **Medium** (**Extra Effort Space**), **High (Physical Synthesis Space)**, **Highest** (**Physical Synthesis with Retiming Space**), and **Selective** (**Selected Performance Optimizations**). As you move from **Low** to **Highest**, the number of options explored by DSE increases, which causes compilation time to increase.

The **Search for Lowest Power** option uses a predefined exploration space that targets overall power improvements for your design. When **Search for Lowest Power** is selected, DSE automatically runs the PowerPlay Power Analyzer for each point in the space. You must ensure that the PowerPlay Power Analyzer is configured correctly to ensure accurate results. DSE issues a warning if the confidence level for any power estimate is low.

The **Search for Best Area** option uses a predefined exploration space that targets device utilization improvements for your design.

Using DSE to Search for the Best Performance

This section describes using DSE to search for the best performance in your design.

Effort Level

When you select **Search for Best Performance** under the **Exploration Settings** in the DSE GUI, you can select the effort level you wish to use to compile your design in DSE. The effort levels are **Low** (**Seed Sweep**), **Medium** (**Extra Effort Space**), **High** (**Physical Synthesis Space**), **Highest** (**Physical Synthesis with Retiming Space**) and **Selective** (**Selected Performance Optimizations**). DSE traverses the points in the exploration space, applies the settings to the design, and compares compilation results to determine the best settings for your design based on your chosen effort level. Search time increases proportionally with the breadth of the options being explored. The exploration space search time increases with the number, type, and combination of options DSE explores.

DSE offers the following exploration space types:

- "Seed Sweep"
- "Extra Effort Space"
- "Physical Synthesis Space"
- "Physical Synthesis with Retiming Space"
- "Selective Performance Optimization"

Seed Sweep

Enter the seed values in the **Seeds** field in the DSE user interface. There are no "magic" seeds. The variation between seeds is truly random, any non-negative integer value is as likely to produce good results. DSE defaults to seeds 3, 5, 7, and 11. The **Low (Seed Sweep)** option exploration space does not change your netlist.

The **Seeds** field accepts individual seed values, for example, 2, 3, 4, and 5, or seed ranges, for example, 2-5.

Each seed value you specify requires an additional compilation. For example, if you enter five seeds, the compilation time increases to 5 times the initial (or base) compilation time.

Extra Effort Space

The **Extra Effort Space** effort level adds the **Register Packing** option to the exploration space done by the **Seed Sweep**. The **Extra Effort Space** effort level also increases the Quartus II Fitter effort during placement and routing. However, the **Extra Effort Space** effort level does not change your netlist.

Physical Synthesis Space

The **Physical Synthesis Space** effort level adds physical synthesis options such as register retiming and physical synthesis for combinational logic to the options included in the **Extra Effort Space** effort level. These netlist optimizations move registers in your design. Look-up tables (LUTs) are modified by these options. However, the design behavior is not affected by these options.

For more information about physical synthesis, refer to the *Netlist Optimizations and Physical Synthesis* chapter in volume 2 of the *Quartus II Handbook*.

Physical Synthesis with Retiming Space

The **Physical Synthesis with Retiming Space** effort level includes all the options in the **Physical Synthesis Space** effort level, and it explores various Quartus II Integrated Synthesis optimization options and register retiming. Register retiming can move registers in your design.

The **Physical Synthesis with Retiming Space** effort level works only for designs that have been synthesized using Quartus II Integrated Synthesis.

Selective Performance Optimization

The **Selective Performance Optimization** effort level combines a seed sweep with various performance Fitter settings to improve the timing of your design. The seed sweep is performed over a limited number of points in such a way that the base settings are not replicated. This is the recommended option for large designs where other spaces may be too large. Use this exploration space for first-time DSE searches on your designs to evaluate the range of results.

Table 14–1 shows the settings adjusted by each effort level.

Table 14–1. Summaries of Effort Levels (Part 1 of 2) *(Note 1)*

Optimization Options	Effort Levels			
	Seed Sweep	Extra Effort	Physical Synthesis	Retiming
Analysis and Synthesis Settings				
Optimization technique	—	—	✓	✓
Perform WYSIWYG resynthesis	—	—	✓	✓
Fitter Settings				
Fitter seed	✓	✓	✓	✓

Table 14–1. Summaries of Effort Levels (Part 2 of 2) *(Note 1)*

Optimization Options	Effort Levels			
	Seed Sweep	Extra Effort	Physical Synthesis	Retiming
Register packing	—	✓	✓	✓
Increase PowerFit Fitter effort	—	✓	✓	✓
Perform physical synthesis for combinational logic	—	—	✓	✓
Perform register retiming	—	—	—	✓

Note to Table 14–1:

(1) For effort levels that include Quartus II Integrated Synthesis Projects, DSE increases the synthesis effort.

DSE Flow Options

You can control the configuration of DSE with the following options:

- Create a Revision from the DSE Point
- Stop Flow When Zero Failing Paths are Achieved
- Continue Exploration Even If Base Compilation Fails
- Run Quartus II PowerPlay Power Analyzer During Exploration
- Archive All Compilations
- Stop Flow After Time
- Skip Base Analysis and Compilation If Possible

Create a Revision from the DSE Point

After you have performed a design exploration with DSE, a Quartus II revision can be made from any exploration point. This option facilitates the creation of multiple revisions based on the same space point for further optimization within the Quartus II software.

Stop Flow When Zero Failing Paths are Achieved

Instructs DSE to stop exploring the space after it encounters any point, including the base point, that has zero failing paths. DSE uses the failing path count reported in the **All Failing Paths report** column to make this decision.

Continue Exploration Even If Base Compilation Fails

With the **Continue Exploration Even If Base Compilation Fails** option turned on, DSE continues the exploration even when a design compilation error occurs. For example, if timing settings are not applied to your design, a DSE error occurs. To cause DSE to continue with the exploration instead of halting when an error occurs, turn on this option.

Run Quartus II PowerPlay Power Analyzer During Exploration

Turn on **Run Quartus II PowerPlay Power Analyzer During Exploration** to run the Quartus II PowerPlay Analyzer for every exploration performed by DSE. Using this option can help you debug your design and determine trade-offs between power requirements and performance optimization.

Archive All Compilations

Turn on **Archive all Compilations** to create a Quartus II Archive File (**.qar**) for each compilation. These archive files are saved to the **dse** directory in the design's working directory.

The result of each DSE run is saved as a **.qar** file in the **dse** subdirectory under your project directory. Each run is identified by a number. The best result of DSE run is saved with the name **best.qar**.

The **dse** directory also contains a spreadsheet (**results.csv**) that compares the results of all the individual runs in your DSE compilation.

Stop Flow After Time

Turn on Stop Flow After Time to stop further exploration after a specified number of days, hours, and/or minutes.

Exploration time might exceed the specified value because DSE does not stop in the middle of a compilation.

Skip Base Analysis and Compilation If Possible

The **Skip Base Analysis & Compilation if Possible** option allows DSE to skip the Analysis and Elaboration stage or the compilation of the base point if base point compilation results are available from a previous Quartus II compilation.

DSE Configuration File

Many options exist that allow you to customize the behavior of each DSE exploration. For example, you can specify seed values or a list of slave computers to be used for a Parallel DSE run. Each time you close the DSE GUI, it saves these values in a configuration file, **dse.conf**. The next time you launch the DSE GUI, it reads the values from **dse.conf** and restores the previous exploration settings.

Where the **dse.conf** file is stored varies depending on the operating system that launches DSE. Table 14–2 specifies the locations where **dse.conf** files are stored.

Table 14–2. DSE Configuration File Location

OS	File Location (default)	Comment
Windows	**%APPDATA%/Altera/dse.conf**	If the variable %APPDATA% is not defined, the configuration file is saved to **%HOME%\.altera.quartus\dse.conf**
Linux	**~/.altera.quartus/dse.conf**	

Settings specified in the DSE command-line mode are not saved to a **dse.conf** configuration file.

Parallel DSE Information

This section covers the **Parallel DSE** option, which enables you to run an exploration on multiple computers concurrently. This feature increases the processing efficiency of design space exploration. You can access the settings for **Parallel DSE** from the Parallel DSE menu in the DSE GUI.

Computer Load Sharing Using Parallel DSE

DSE uses cluster computing technology to decrease exploration time when you click **Distribute Compilations to Other Machines** (on the Parallel DSE menu). DSE uses multiple client computers to compile points in the specified exploration space.

Parallel DSE functions in one of the following modes:

- **Use LSF Resources**—DSE uses the Platform LSF grid computing technology to distribute exploration space points to a computing network.
- **Use QSlave**—This function uses a Quartus II master process. DSE acts as a master and distributes exploration space points to client computers.

When you use the **Distribute Compilations to Other Machines** option, different exploration points in the exploration space are compiled on different slave client computers at the same time. Concurrent compilations requires a separate license for each instance of the Quartus II software being used to compile the design. Each compilation also might require licenses for any IP cores in the design. Therefore, the number of parallel distributed compilations can be limited to the number of licenses available for the Quartus II software or the IP core used in your design.

Parallel DSE Using LSF Resources

The easiest way to use distributed DSE technology is to submit the compilations to a preconfigured LSF cluster at your local site. For more information about LSF software, refer to www.platform.com, or contact your system administrator. To run Parallel DSE using LSF resources, on the Parallel DSE menu, click **Configure Resources**.

Parallel DSE Using a Quartus II Master Process

Before DSE can use computers in the local area network to compile points in the exploration space, you must create Quartus II software slave instances on the computers that will be used as clients. Type the following command at a command prompt on a client computer:

```
quartus_sh --qslave ↵
```

Repeating this command on several computers creates a cluster of Quartus II software slaves for DSE to use. After you have created a set of Quartus II software slaves on the network, add the names of each slave computer in the **QSlave** tab of the **Configure Resources** dialog box.

To access the **Configure Resources** dialog box, on the Parallel DSE menu, click **Configure Resources**. To add resources, click the **QSlave** tab and click **Add** and type the client name. Click **OK**.

At the start of an exploration, DSE assumes the role of a Quartus II software master process and submits points to the slaves on the list to compile. If the list is empty, DSE issues an error and the search stops.

☞ For more information about running and configuring Quartus II slaves, type the following command at the command prompt:

```
quartus_sh --help=qslave ↵
```

Parallel DSE uses a protocol based on FTP to move files between the master and the slaves. By default, the qslave client listens to port number 1977 for communication with the master. If you are running a firewall on a computer that is running the qslave client, make sure you configure the firewall software such that it allows incoming and outgoing transmission control protocol (TCP) and user datagram protocol (UDP) packets on the port used by qslave.

You must set this configuration in every computer that is used as a slave in a distributed DSE environment.

☞ You can change the default port number used by qslave by typing the following command at a command prompt:

```
quartus_sh --qslave port=<new_port_number> ↵
```

You must use the same version of the Quartus II software to run the slave processes as you use to run DSE. To determine which Quartus II software version you are using to run DSE, select Help and click **About DSE.** Unexpected results can occur if you mix different Quartus II software versions when using the Parallel DSE feature.

☞ When you are using ClearCase revision control software, Parallel DSE compilations launched within a ClearCase view might fail. ClearCase catches system I/O calls that can prevent communication between the DSE master and its slave computers. To avoid this problem, run Parallel DSE outside of the ClearCase environment.

Concurrent Local Compilations

To reduce compilation time, DSE can compile exploration points concurrently. The **Concurrent Local Compilations** option allows you to specify up to six concurrent compilations by choosing an integer value ranging from 0 through 6. You can use this option in conjunction with Parallel DSE. However, your system must have the appropriate resources and licenses to perform concurrent compilations, and distributed processing. Multiprocessor or multicore systems are recommended for concurrent local compilations.

☞ **Concurrent Local Compilations** require a separate Quartus II software license for each concurrent compilation. For example, if you compile four concurrent compilations, you must have four licenses. Ensure that sufficient licenses are available before you choose a **Concurrent Local Compilations** value and start compilation.

You can use Concurrent compilations and the distributed compiles with other computer options at the same time if you use the QSlave approach for distributing compiles to other computers.

If you use LSF, all the jobs are submitted to the LSF system.

Referenced Documents

This chapter references the following documents:

- *Managing Quartus II Projects* chapter in volume 2 of the *Quartus II Handbook*
- *Netlist Optimizations and Physical Synthesis* chapter in volume 2 of the *Quartus II Handbook*
- *Quartus II Integrated Synthesis* chapter in volume 1 of the *Quartus II Handbook*

Document Revision History

Table 14–3 shows the revision history for this chapter.

Table 14–3. Document Revision History (Part 1 of 2)

Date and Document Version	Changes Made	Summary of Changes
March 2009 v9.0.0	■ Was chapter 12 in the 8.1.0 release. ■ Updated Table 14–1 and Table 14–2 . ■ Added the following sections: → "Project Uses Quartus II Integrated Synthesis" on page 14–5 → "Exploration Settings" on page 14–5 → "Effort Level" on page 14–6 ■ Updated the following sections: → "General Description" on page 14–2 → "Setting Up the DSE Work Environment" on page 14–5 → "Seed Sweep" on page 14–6 → "Physical Synthesis Space" on page 14–7 → "Concurrent Local Compilations" on page 14–11 ■ Deleted the following sections: → Ignore SignalTap and SignalProbe Settings → Quartus II Integrated Synthesis → Search fir Best Performance, Search for Best Area Options, or Search for Lowest Power Option	Updated for the Quartus II software version 9.0 release.

Table 14–3. Document Revision History (Part 2 of 2)

Date and Document Version	Changes Made	Summary of Changes
November 2008 v8.1.0	Changed to 8½" x 11" page size. No change to content.	Updated for the Quartus II software version 8.1 release.
May 2008 v8.0.0	Updated the following sections: ■ "Search for Best Performance, Search for Best Area Options, or Search for Lowest Power Option" on page 12–5 ■ "Using the DSE to Search for the Best Performance" on page 12–6 ■ "Physical Synthesis with Retiming Space" on page 12–7 ■ "Parallel DSE Information" on page 12–10 Deleted the following sections: ■ Advanced Search Options ■ Exploration Space ■ Custom Space ■ Area Optimization Space ■ Change Decision Column ■ Save Exploration Space to File ■ Creating Custom Spaces for DSE	—

For previous versions of the *Quartus II Handbook*, refer to the Quartus II Handbook Archive.